MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1990

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries tenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1990, ninety-seven sampling trips were made aboard commercial lobster vessels. A total of 48,868 lobster was sampled from 16,159 trap hauls. The catch rate of marketable lobster, 0.826 lobster per trap, was 10% higher than the 1989 index, 0.751. The proportion of females ovigerous, 10.9%, was significantly larger than in the previous year (10.1%). Coastwide fishing mortality and exploitation rates were similar to 1989 data. Mean carapace length of marketable lobster, 89.0 mm, was comparable to mean size measured in 1989. The percentage of culls declined from 19.2% in 1989 to 16.6% in 1990. As observed in previous years, less than 1% of the lobster sampled from traps were dead.

The incidence of V-notched lobster in Massachusetts coastal waters was described by number and weight for the period 1984-1990. Annual and regional trends are discussed. The regulating of a V-notch definition in 1990 to standardize interpretation of the law by fishermen and law enforcement agents was assessed. The impact of V-notch protection on fishermen, through loss of landings, was significantly reduced in 1990 by the definition.

An assessment was made of the impact of the total 1.59 mm increase in minimum C.L. in this third, non-gauge increase, year (1990) of the five-year program. The improvements in the relative proportions of lobster in the market weight categories appeared to stabilize in 1990. Increased catch rates of egg-bearing females by 10 mm size groups were again observed during 1990.

Shell disease was investigated in six coastal Massachusetts sites. A total 4,791 lobster were collected via commercial lobster sea sampling during May through November, 1989 and 4225 during the same months in 1990. The effect of a number of variables on shell disease prevalence was evaluated in order to standardize assessments of the condition.

Disease symptoms were not uniformly distributed throughout the lobster length range. Prevalence was highest and severity greatest in the larger size groups indicating an inverse relationship with molt frequency. This correlation was significant for hardshelled lobster but not for newshelled lobster. Significant differences in disease prevalence were observed between the sexes. This was primarily due to the high level of disease observed among ovigerous females. However, mature non-ovigerous females also exhibited a significantly greater frequency of symptoms than males.

These factors are important considerations in comparative analyses. Samples used in trend studies should be standardized according to size, sex, ovigerous and molt condition, and severity.

Effects of temperature on annual lobster landings and catch per pot were investigated using transfer function analyses. Several series of annual and seasonal temperature had significant immediate and lagged effects.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) tenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling-survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1990 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1990 study period are presented.

Shell disease was also monitored during commercial lobster sea sampling. This disease commonly occurs in marine and fresh water crustaceans. Its etiology is characterized by a deterioration of the chitinous exoskeleton by chitinoclastic (chitin-consuming) microorganisms which gradually erode and pit the shell and in advanced cases uncover the epithelium, and create necrotic lesions (Malloy 1978; Sindermann 1970; Rosen 1970; Dow et al. 1975; Stewart 1980). Bacteria and fungi have been implicated; however, several species of the bacterial genera, *Vibrio, Aeromonas,* and *Pseudomonas,* are most often cited as causative agents (Getchell 1989, Sindermann 1989).

Shell disease can impact the marketability of crustacean species by creating an unsightly appearance, weakness, and elevated mortality. The purpose of monitoring was to determine background levels and to define the variables which affect shell disease prevalence and thereby standardize estimates of it.

An ancillary investigation of the effect of temperature on lobster catch statistics was undertaken because the biology of the American lobster is highly sensitive to changes in ambient temperature. Variation in seawater temperature has profound influence on growth, survival, and behavior at each stage of the lobster's life cycle (e.g. embryonic development: Aiken 1980, and Harding *et al.* 1983; larval development and survival: Hadley 1906, Templeman 1936a and 1936b, Templeman and Tibbo 1945, Caddy 1979, Harding *et al.* 1983, and Ennis 1986; juvenile and adult growth: Templeman 1936a and 1948, Aiken 1980, Campbell 1983, and Ennis 1986; sexual maturity: Templeman 1936b, Aiken and Waddy 1986, and Estrella and McKiernan 1989; migratory behavior: Cooper and Uzmann 1971, and Campbell 1986; and catchability: McLeese and Wilder 1958, Stewart *et al.* 1972, and Ennis 1984). Temperature also affects the lobster indirectly by regulating the productivity of prey and predator populations, prevalence of diseases, and hydrographic conditions (Templeman 1936a and 1936b, Caddy 1979, Harding *et al.* 1983, and Fogarty 1988). Since temperature influences abundance and catchability of lobster, it has been successfully used as a factor to explain and predict trends in lobster landings (Taylor *et al.* 1957, Dow 1961, 1976, 1977, and 1980, Flowers and Saila 1972, Orach-Meza and Saila 1978, Harding *et al.* 1983, and Fogarty 1988).

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann,

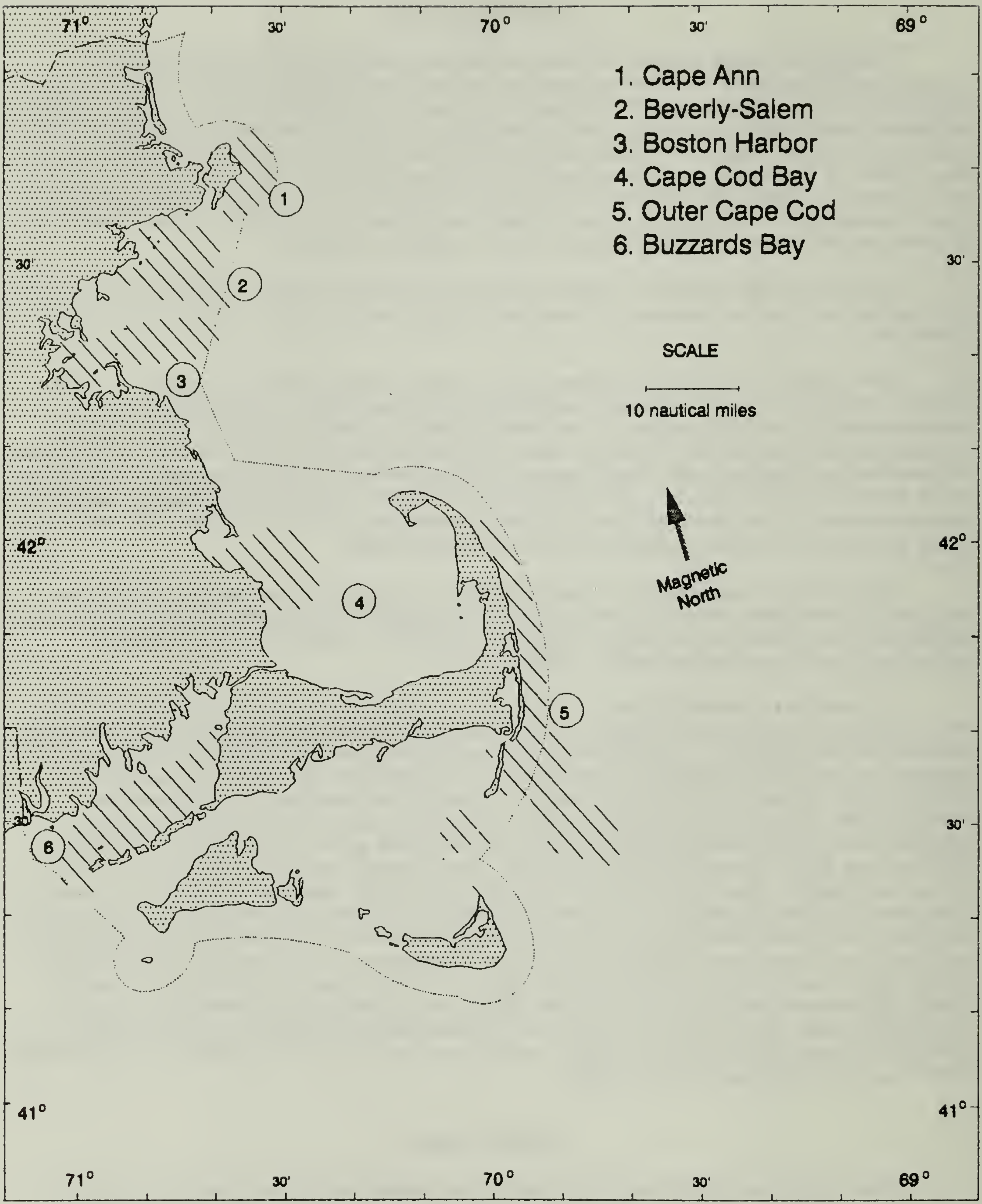


Figure 1. Map of Massachusetts coast with six sampling regions (hatch-marked) and territorial sea boundary (stippled).

Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm and to the nearest 0.1 mm between 81.5 and 82.5 mm to establish the minimum legal size of 82.55 mm, 3.25"); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations and depths were recorded from LORAN and depth sounder equipment when available on vessels.

In 1989, the disease monitoring segment of the program was modified by incorporating a subsampling technique in which approximately 50 lobsters were sampled per trip. The last trawl (or two depending upon lobster density) hauled per day was sampled for shell disease and associated biological data only. This allowed adequate time to discern shell disease symptoms and thereby improve data quality.

Standardization of lobster shell disease sampling and symptom evaluation was attempted to allow comparative or trend analyses. The variables of lobster size, sex, condition, including molt stage and presence of eggs (brown = developing, green = newly extruded), severity of symptoms, and anatomical location were noted. Shell disease symptoms were categorized as minor pitting: single or multiple pits or infected pores with localized shell discoloration (dark brown or black) and deterioration; erosion: merging or connecting of localized pits and tunneling via chitinolytic activity; or ulceration: when extensive erosion has destroyed the chitinous layers and uncovered underlying tissue resulting in secondary infection.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred to the Woods Hole Oceanographic Institution's Digital Equipment Corporation VAX-11/780 computer system for analysis. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

The Kolmogorov-Smirnov two sample test and Mann-Whitney U/Wilcoxon W tests were used to determine the significance of year to year variation in parameters.

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females and, since 1988, also excludes V-notched females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with Cohort Analysis (Pope 1972). Rates of exploitation were calculated with the equation u=FA/Z, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

Pearson's r correlation coefficients were computed to determine the interdependence of variables. Duncan's multiple range test (Steele and Torrie 1960) was used to determine pairs of stations significantly different at the 0.05 alpha level. The Mann-Whitney U-Wilcoxon Rank Sum W two-sample test (Sokal and Rohlf 1969) was applied to examine the effects of variables on disease incidence.

Transfer function analysis (Box and Jenkins 1976) was used to predict lobster landings based on temperature. Output and predictor variables with significant trends were made stationary by first order differencing (i.e. a series "y" that has a substantial net change during the time period is transformed to a de-trended series "z" by subtracting the previous value, so that $z_t = y_t - y_{t-1}$). Log_e transformations were used to alleviate heteroscedasticity in landings and catch per pot. Based on autocorrelation (*i.e.* the association of serial observations at various time lags) and partial autocorrelation (*i.e.* autocorrelation with the effects of intervening lags removed), variables were modelled using autoregressive methods (i.e. regression of a series using lagged values of the same series as a predictor variable, also termed an autoregressive integrated moving average, ARIMA, model). An ARIMA model was developed for the predictor series and used to filter the predictor and the output variables. Crosscorrelation analysis (*i.e.* testing the relationships between predictor and output variables at specific lags) was performed on residuals from the univariate autoregressive predictor model and the filtered output model. Transfer function parameters, defined by crosscorrelation plots, were then added to the output ARIMA model. Significance of autoregressive and transfer function effects were assessed by t-ratios of the coefficients. Diagnostic routines were performed on the residuals to test for deviation from white noise (*i.e.* random oscillation), correlation with predictor series, and normality using the Shapiro-Wilk statistic.

RESULTS AND DISCUSSION

Commercial Sea Sampling

During the period of May through November, 1990, ninety-seven sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 48,868 lobster was sampled from 16,159 trap hauls.

The 1990 coastwide mean catch per unit effort index (CTH'_3), 0.826 marketable lobster per trap, was 10% higher than the 1989 index, 0.751 (Appendix Table 1). Total Massachusetts commercial landings, 16,720,924 lbs, increased by 14% from 1989. Landings from territorial waters, 12,307,760 lbs., increased by 19%; however, this substantial increase may be artificially inflated since it coincides with a change in the reporting system and fishing area designations which more accurately depict the Massachusetts territorial sea. Previous landings statistics for territorial waters were estimated. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster differed significantly between 1989 and 1990 (Appendix Tables 2 and 3). CTHAUL was lower and CTHSOD was higher in 1990.

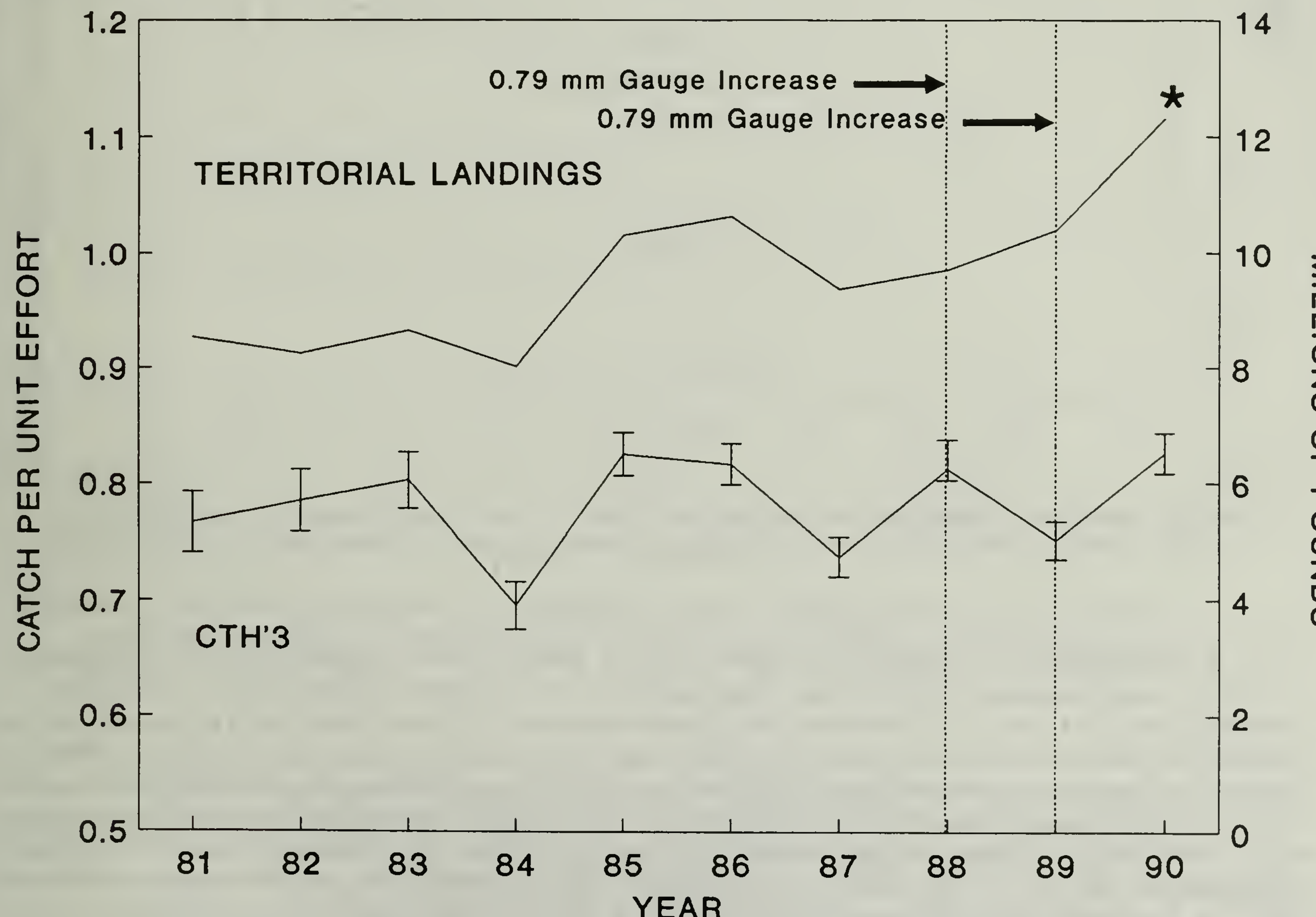


Figure 2. Catch per unit effort of marketable American lobster from commercial lobster trap sampling and Massachusetts lobster landings from territorial waters, 1981-1990. Asterisk indicates a change in the landings reporting system for 1990.

Of all females sampled during 1990, 10.9% were ovigerous compared to 10.1% in 1989 (Appendix Table 4). A significant difference was observed between years (P = 0.0004). Trends in abundance of ovigerous females are depicted in Figure 3 (Appendix Tables 4-6).

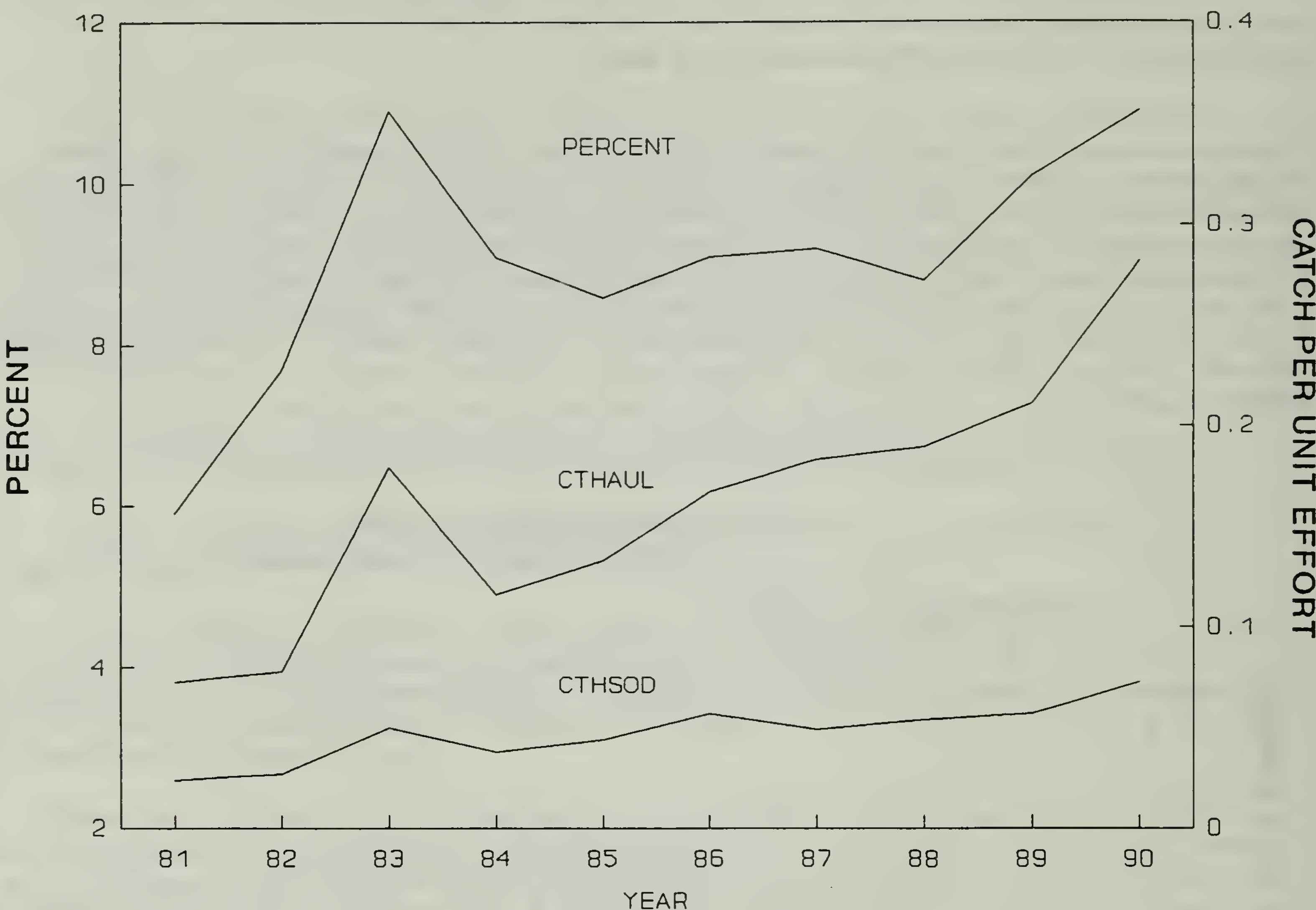


Figure 3. Relative abundance of ovigerous female American lobster in percent of total females and catch per unit effort, Massachusetts coastal waters, 1981-1990.

Fishing pressure indices decreased slightly during 1990 compared to 1989 (Appendix Table 7). Approximately 92% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits, i.e., lobster which recruited to the legal size range during their most recent molt compared to 93% in 1989. The index fluctuated from 47% to 50% for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) were also high, but they did not change much from 1989. Indices for inshore Gulf of Maine regions (Z = 1.39-3.00, A = 75%-95%) and Buzzards Bay (Z = 2.27-2.60, A = 90%-93%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.62, A = 47%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.51 off outer Cape Cod to 1.97 in Buzzards Bay (Appendix Table 9). Estimates did not differ greatly from those observed the previous year. Exploitation rates (*u*), i.e. the fraction of the population that is removed by fishing were also similar to 1989 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter carapace length increases of 0.7 mm occurred in 1988 (88.2 mm) and 1989 (88.9 mm, Appendix Table 11) which probably reflected the similar numerical change in the minimum legal size during those years. Fishing mortality and exploitation rates appeared to stabilize accordingly. Measurements of all three indicators in 1990 were consistent with 1989 data.

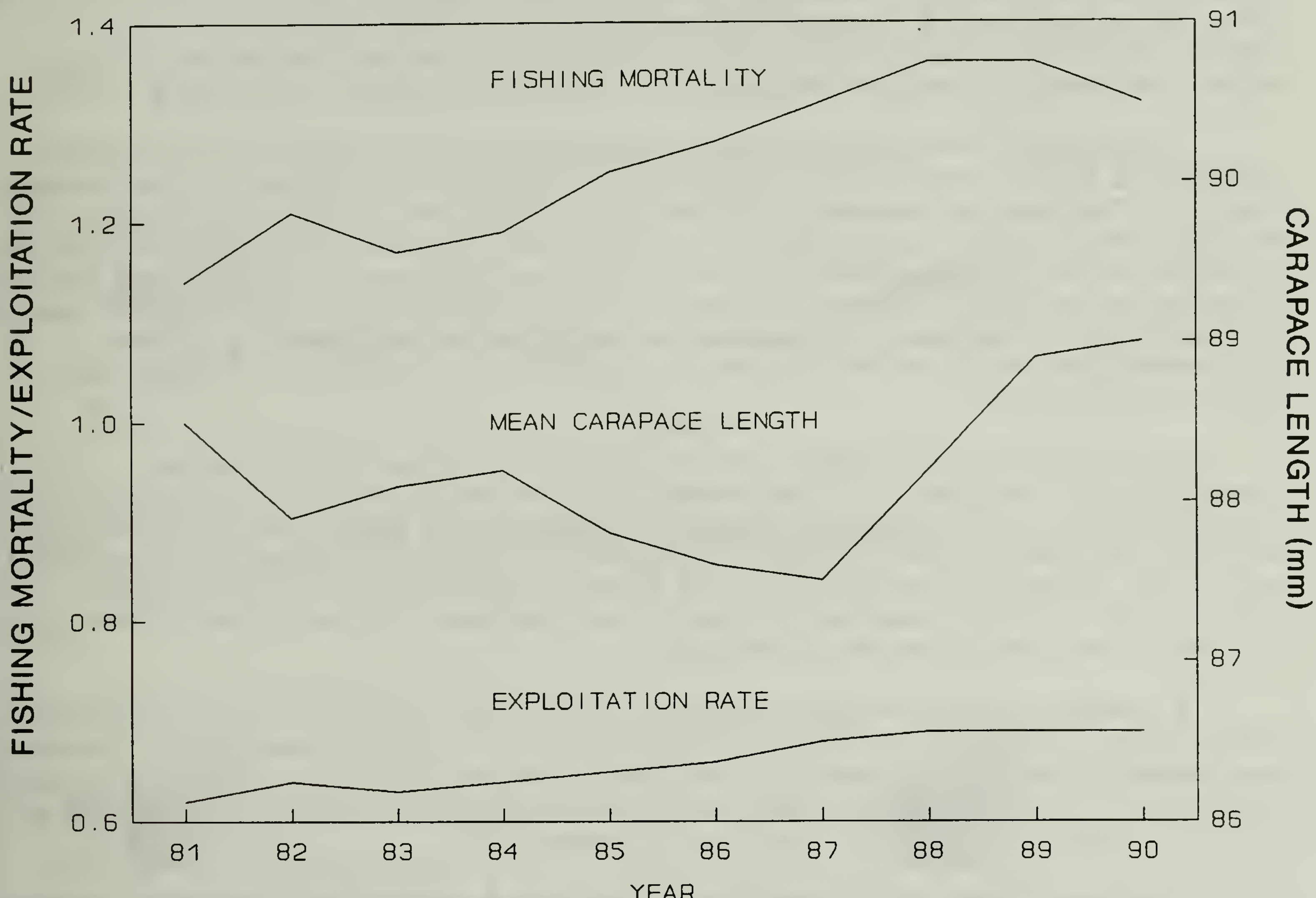


Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1990.

Sublegal sized lobster averaged 77.6 mm carapace length during 1990 compared to 77.5 mm during 1989 (Appendix Table 12). The mean size of all ovigerous females decreased from 88.5 mm in 1989 to 88.0 mm in 1990 ($P < 0.001$, Appendix Table 13). The significant difference is primarily due to changes in the size distribution between the two years. A greater number of sublegal sized eggers were observed in 1990.

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled declined from 19.2% in 1989 to 18.6% in 1990 (Appendix Table 14). The cull rates for legal, marketable, and sublegal size groups were similar to 1989 observations (Appendix Tables 15-17).

The coastwide incidence of lobster found dead in traps was < 1%. This was consistent with the previous year's data (Appendix Table 18).

V-Notched Lobster

Since 1984 we have monitored the incidence of V-notched females in the commercial catches sampled in Massachusetts coastal waters (Estrella and McKiernan 1989). We infer from the knowledge of lobster movement acquired from tagging studies, that the majority of V-notched females observed originated in Maine where V-notching is an industry-sponsored practice. Maine state officials purchase and release female lobster that extrude eggs while in captivity at dealerships or coastal impoundments. Before release, the lobster are marked with a V-shaped cut in the right endopodite uropod (tail flipper to the right of center when head is facing away). This brands them as illegal to take. Many Maine lobstermen, although not required, also V-notch trap-caught egg-bearing females.

Beginning in 1941, Massachusetts DMF personnel were required to V-notch and return to sea female lobster after egg hatching occurred at the DMF hatchery on Martha's Vineyard. This law was amended on 30 March, 1959 to allow all licensed fishermen to V-notch egg bearing lobster voluntarily. The statute was repealed on 27 April, 1973 because of fear of gaffkemia induction at the wound site and a growing sentiment among managers and scientists that there were more definitive and measurable ways to manage the resource. Although a few Massachusetts fishermen continued to practice V-notching, it was considered highly unlikely that they could account for the number of V-notched females observed in our studies.

On 1 January, 1988, V-notch protection once again became regulated in Massachusetts. This occurred in conjunction with the New England Fishery Management Council's implementation of the gauge increase program and extension of V-notch lobster protection throughout federal waters. The premise of uniform management throughout the range of the lobster was thereby supported by the adoption of this FMP amendment. Fishermen are currently required to return V-notched females to sea; however, there is no provision in the law for renewal of notching.

V-notched females are most abundant in two of the six Massachusetts coastal regions sampled, Cape Ann and outer Cape Cod (Figure 5). This is due to the migratory nature of these generally large mature lobster in the Gulf of Maine. They seasonally enter the deep water near Cape Ann and outer Cape Cod from which they move into adjacent shoals as the water temperature rises in the spring and summer.

V-notched lobster are generally larger than the normal marketable lobster, because the size at 50% maturity for northern Gulf of Maine females (the assumed source of most notched females) is approximately 100 mm CL. It is therefore desirable to express the proportion of lobster V-notched by weight as well as by number to assess the impact of the V-notch protection law on landings.

The following regional weight-length relationships were derived from 4,933 non-cull observations which were originally reported by Estrella and McKiernan (1989):

Southern Gulf of Maine	Males	$WT = 0.000344 \times CL^{3.1900}$
	Females	$WT = 0.001167 \times CL^{2.9194}$
Outer Cape Cod	Males	$WT = 0.000883 \times CL^{2.9868}$
	Females	$WT = 0.002114 \times CL^{2.7990}$
Buzzards Bay	Males	$WT = 0.000162 \times CL^{3.3762}$
	Females	$WT = 0.001575 \times CL^{2.8697}$

These equations were used to calculate weights for all legal-sized lobster measured during commercial trap sampling from 1984-1990 by sex, region, and cull condition. Predicted

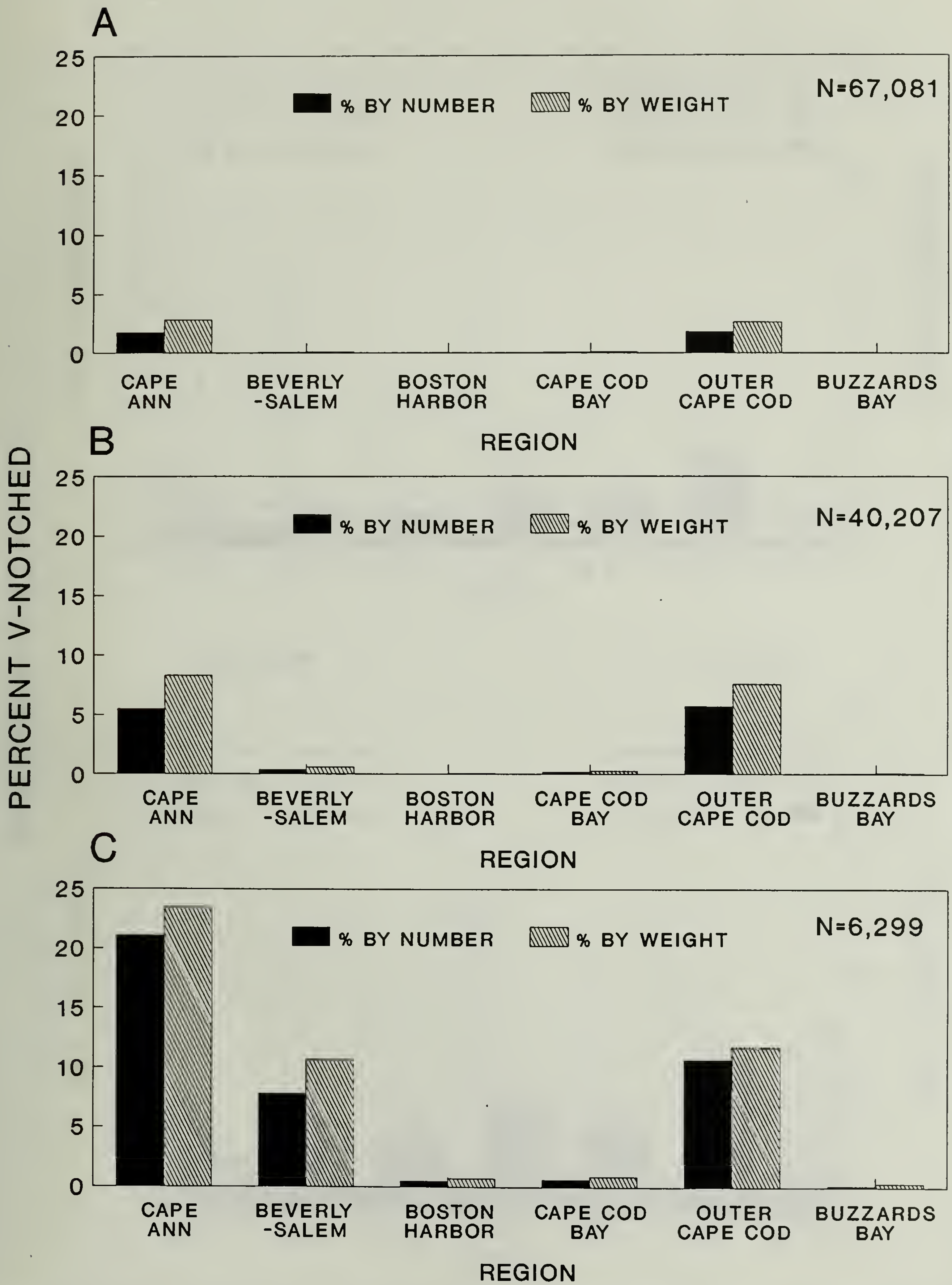


Figure 5. Percent of V-notched American lobster in marketable (A), legal-sized female (B), and legal-sized ovigerous female (C) categories by region, Massachusetts coastal waters, 1984-1990.

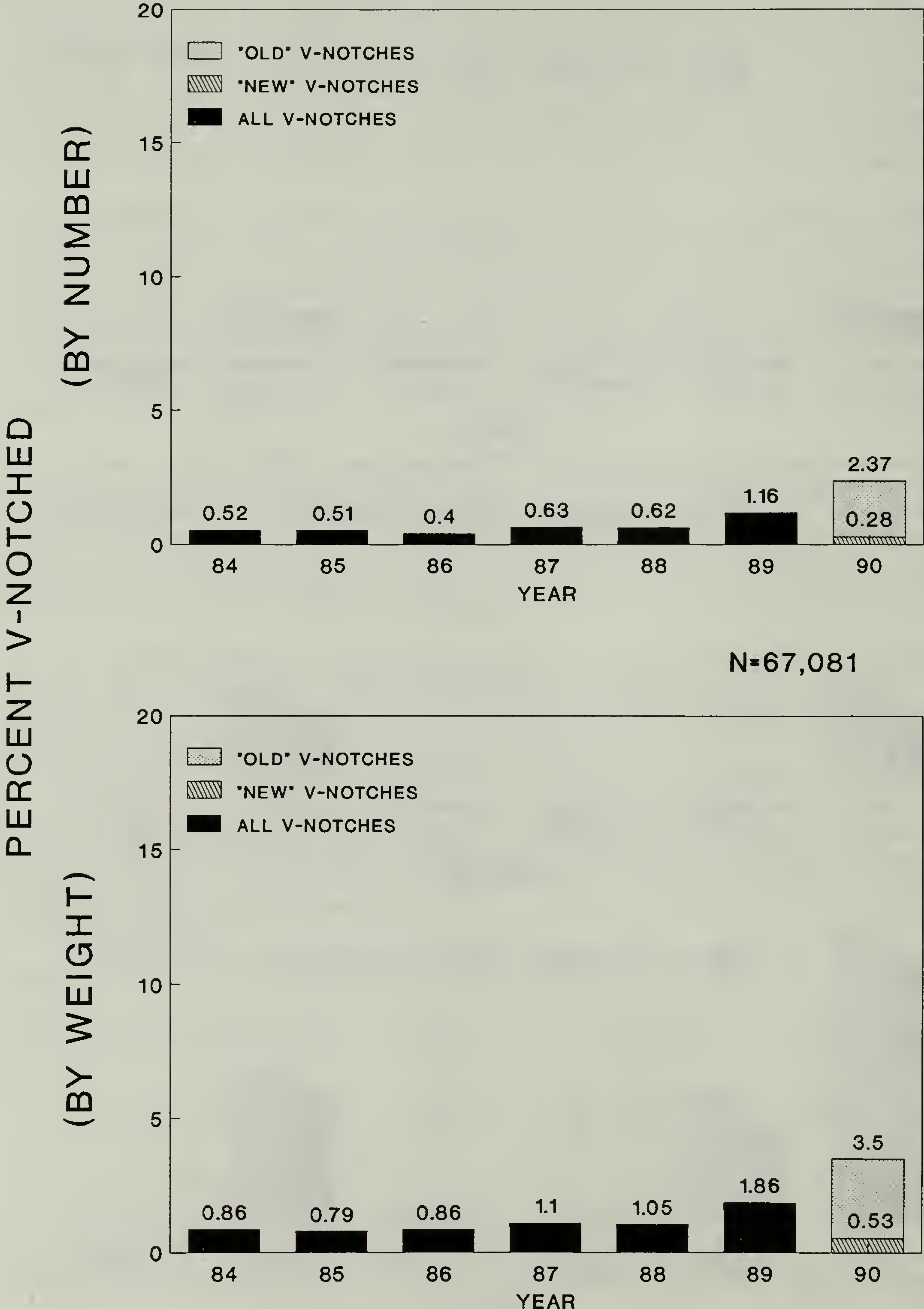


Figure 6A. Percent of marketable American lobster V-notched by year, Massachusetts coastal waters, 1984-1990.

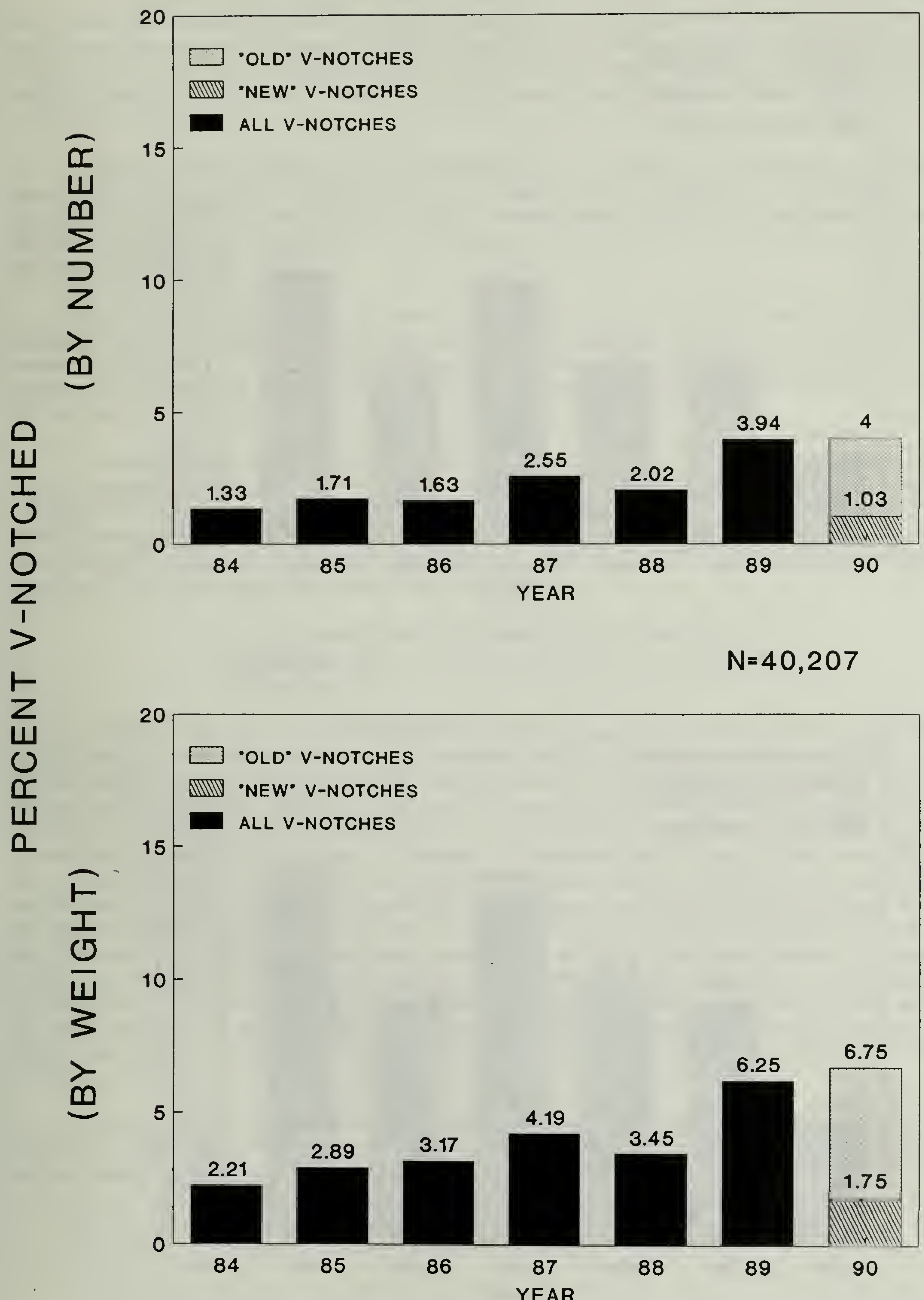


Figure 6B. Percent of legal-sized female American lobster V-notched by year, Massachusetts coastal waters, 1984-1990.

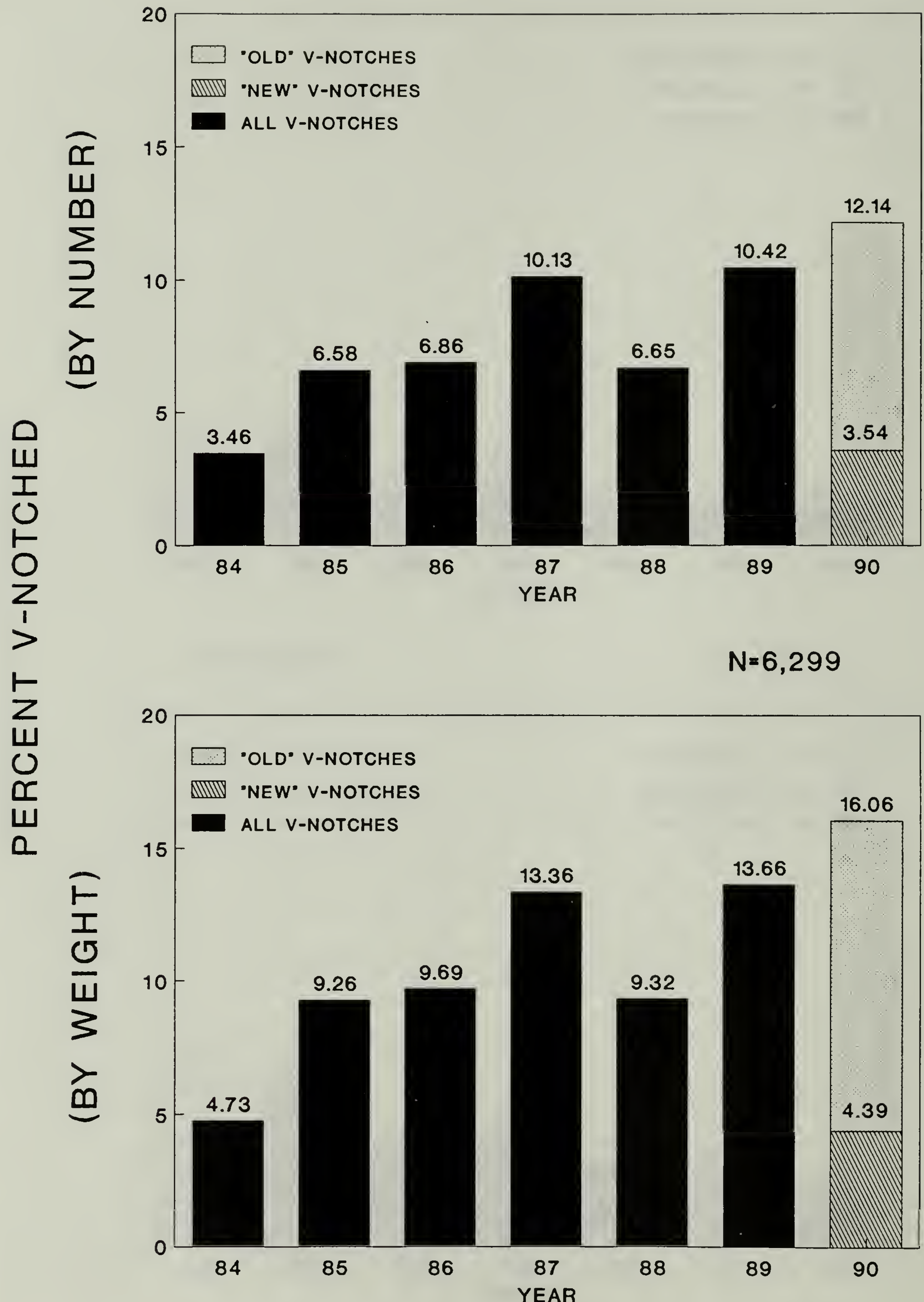


Figure 6C. Percent of legal-sized ovigerous female American lobster V-notched by year, Massachusetts coastal waters 1984-1990.

weights were then reduced for lobster with missing or regenerating claws according to cull lobster weight deficits calculated by Krouse (1976).

V-notched females represented from 0.4 to 1.16 % (0.79-1.86% by weight) of the coastwide marketable catch (less eggers) between 1984 and 1989 (Figure 6A). The coastwide proportion of legal-sized females with V-notches ranged from 1.33 to 3.94% (2.21-6.25% by weight) during the six-year period (Figure 6B). The percentage of legal-sized egg bearing females (Figure 6C) with V-notches was higher ranging from 3.46 to 10.42% (4.73-13.66% by weight).

The overall increase in V-notched lobster observed in 1989 (Figure 6) may have been due to the impact of law enforcement and fishermen's compliance in the discard of V-notched females. This would make these lobster more visible in subsequent catches. However, some local lobstermen have renewed the practice of V-notching thus augmenting the number available.

Analyses of 1989 data by month (Estrella and Cadrin 1990) generally showed that V-notched lobster abundance tends to peak around mid-summer. This is likely due to annual inshore movement of lobster into warmer shoal water. In mid-summer 1989, V-notched lobster represented as much as 8-10% of the marketable catch in number of lobster (10-15% by weight) in the Cape Ann and outer Cape Cod regions.

Industry concerns about variable interpretation and enforcement of the V-notch law and its impact on catches, particularly in the Outer Cape Cod region where large lobster predominate, led to the refining of the V-notch definition. In order to reduce confusion due to the potentially significant changes in the morphology of the V-notch which can occur from healing, molting, and shell disease, the Marine Fisheries Advisory Commission approved the following definition in April 1990:

> *"... a straight-sided triangular cut without setal hairs, at least 1/4 inch in depth and tapering to a sharp point."*

The application of this definition to lobster sampled during 1990 produced significantly lower proportions of V-notched lobster than in previous years ($P < 0.001$, G-test of independence, Figures 6A-6C, Figures 10A-10F). Peak abundance of V-notched lobster at mid-summer 1990 was reduced (Figures 7-9). Only 2-3% of the marketable catch in number of lobster (4-5% by weight) in the Cape Ann and Outer Cape Cod regions were V-notched. Annual proportions of lobster (by number and weight) observed with V-notches were compared by region and size category (Figure 10A-F). In nearly all cases the proportion of newly defined V-notched lobster were significantly lower than in 1989. Of all marked lobster in the marketable size category, only 0.28% by number (0.53% by weight) met the new V-notch definition and were now excluded from the market. A total 1.03% (1.75% by weight) of legal-sized females and 3.54% (4.39 % by weight) of the ovigerous females were defined as V-notched. These statistics represent only 12%, 26%, and 29% of the total number of marketable, legal sized female, and ovigerous female lobster which would have been labeled as V-notched by the old "any mark goes" definition (15%, 26% and 27% by weight).

Statistical testing of the proportion V-notched in 1989 vs 1990 (with 1990 notches determined by 1989 standards) resulted in no significant differences observed among the three lobster categories ($P > 0.50$).

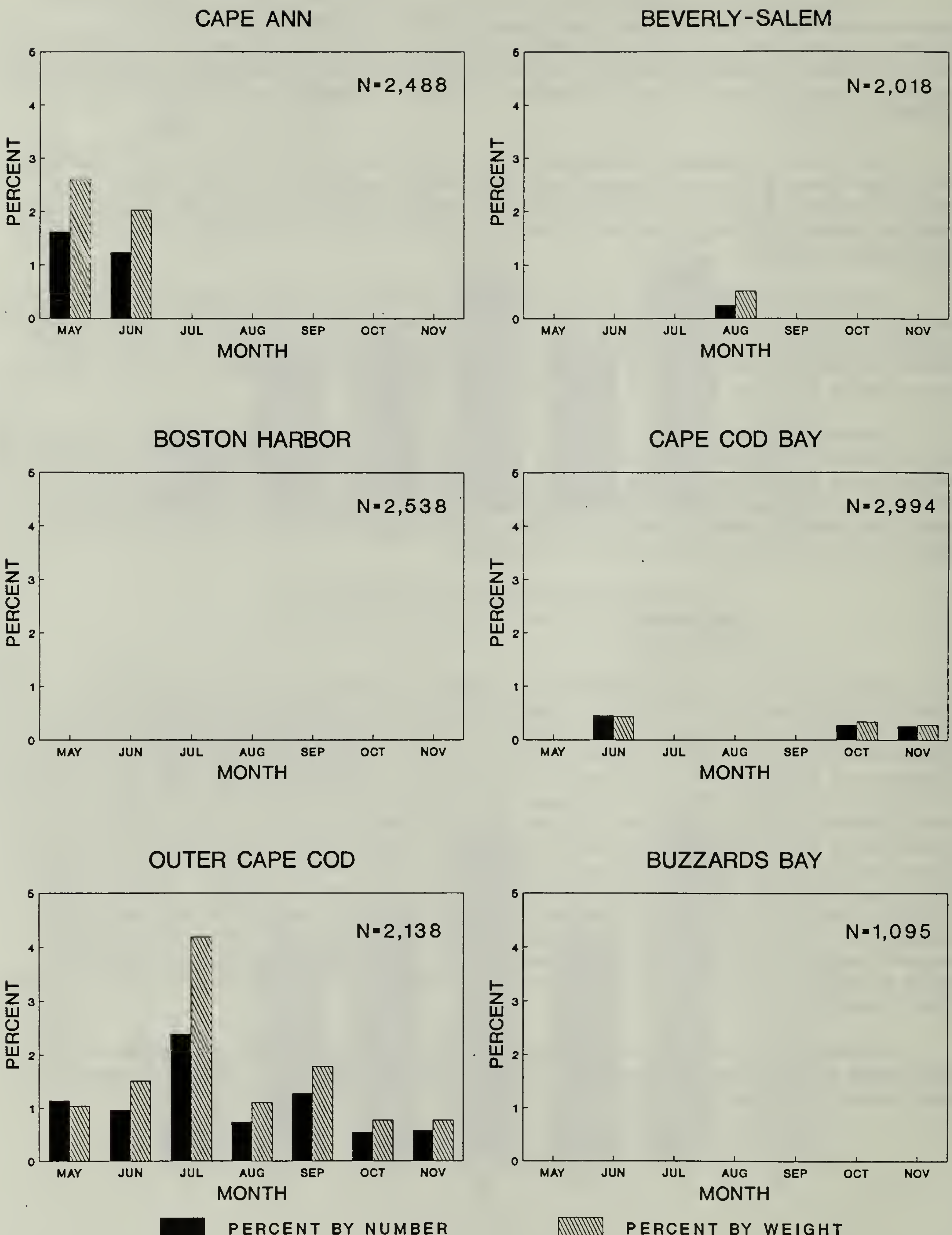


Figure 7. Percent of marketable American lobster with V-notches by region and month, Massachusetts coastal waters, 1990.

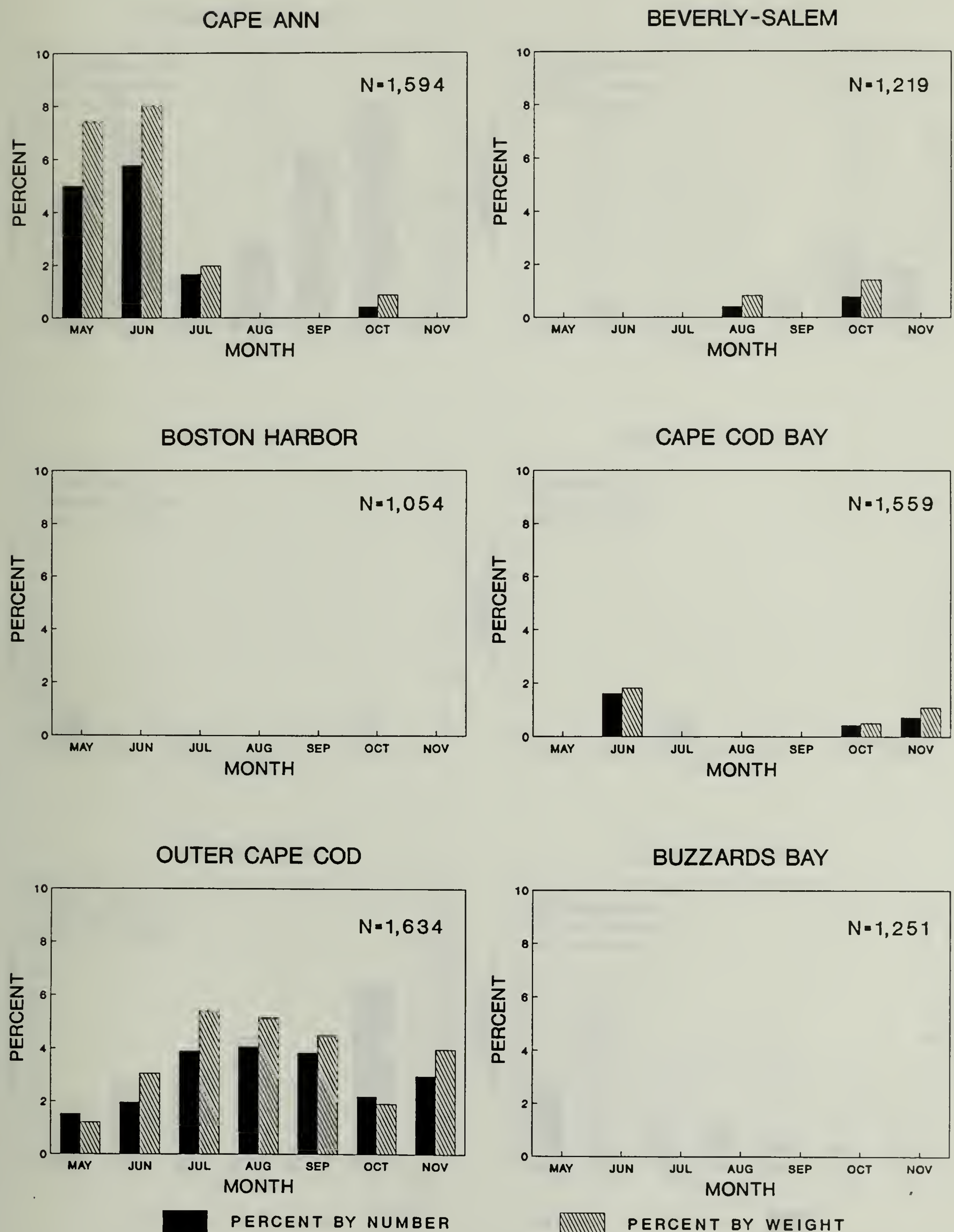


Figure 8. Percent of legal-sized female American lobster with V-notches by region and month, Massachusetts coastal waters, 1990.

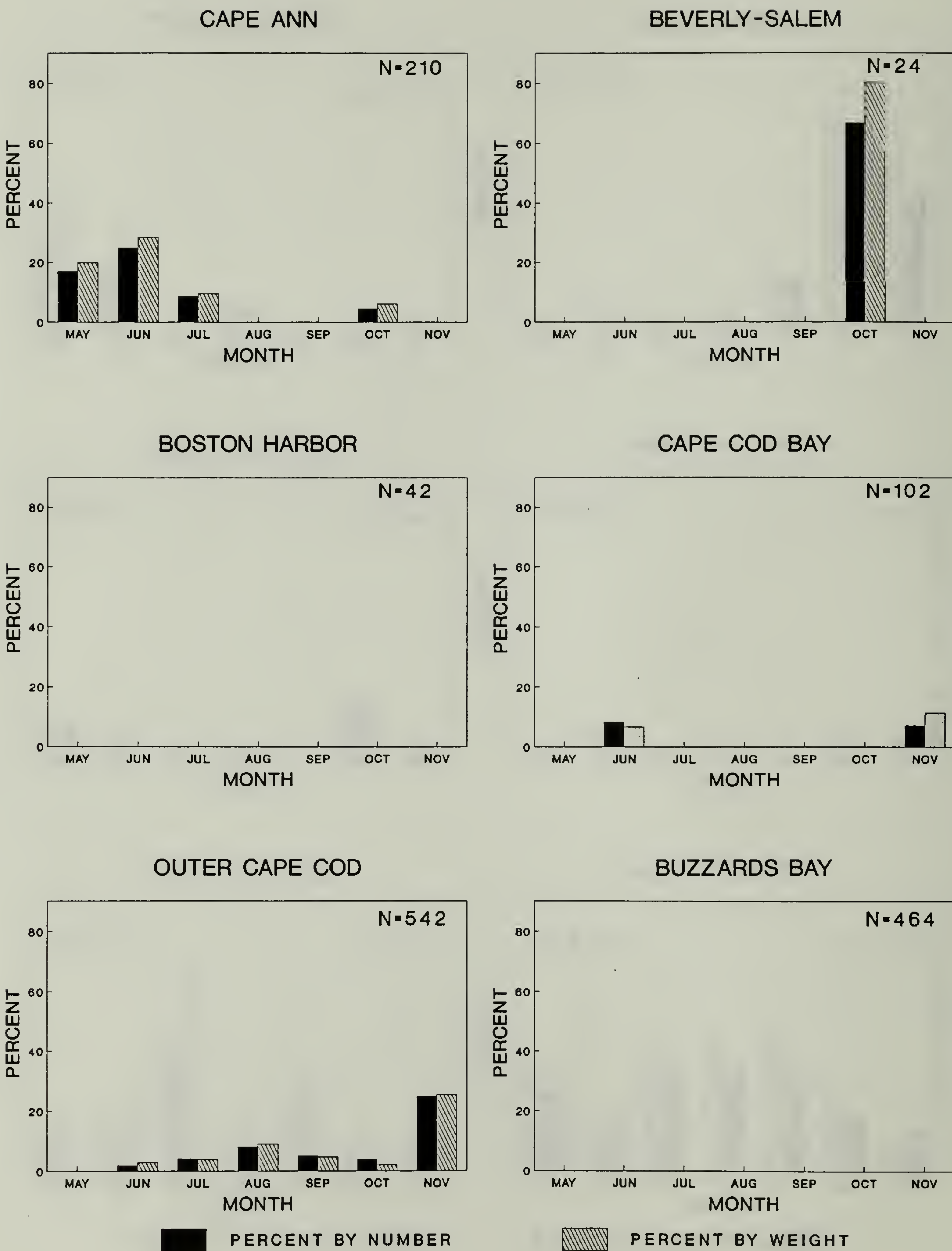


Figure 9. Percent of legal-sized ovigerous female American lobster with V-notches by region and month, Massachusetts coastal waters, 1990.

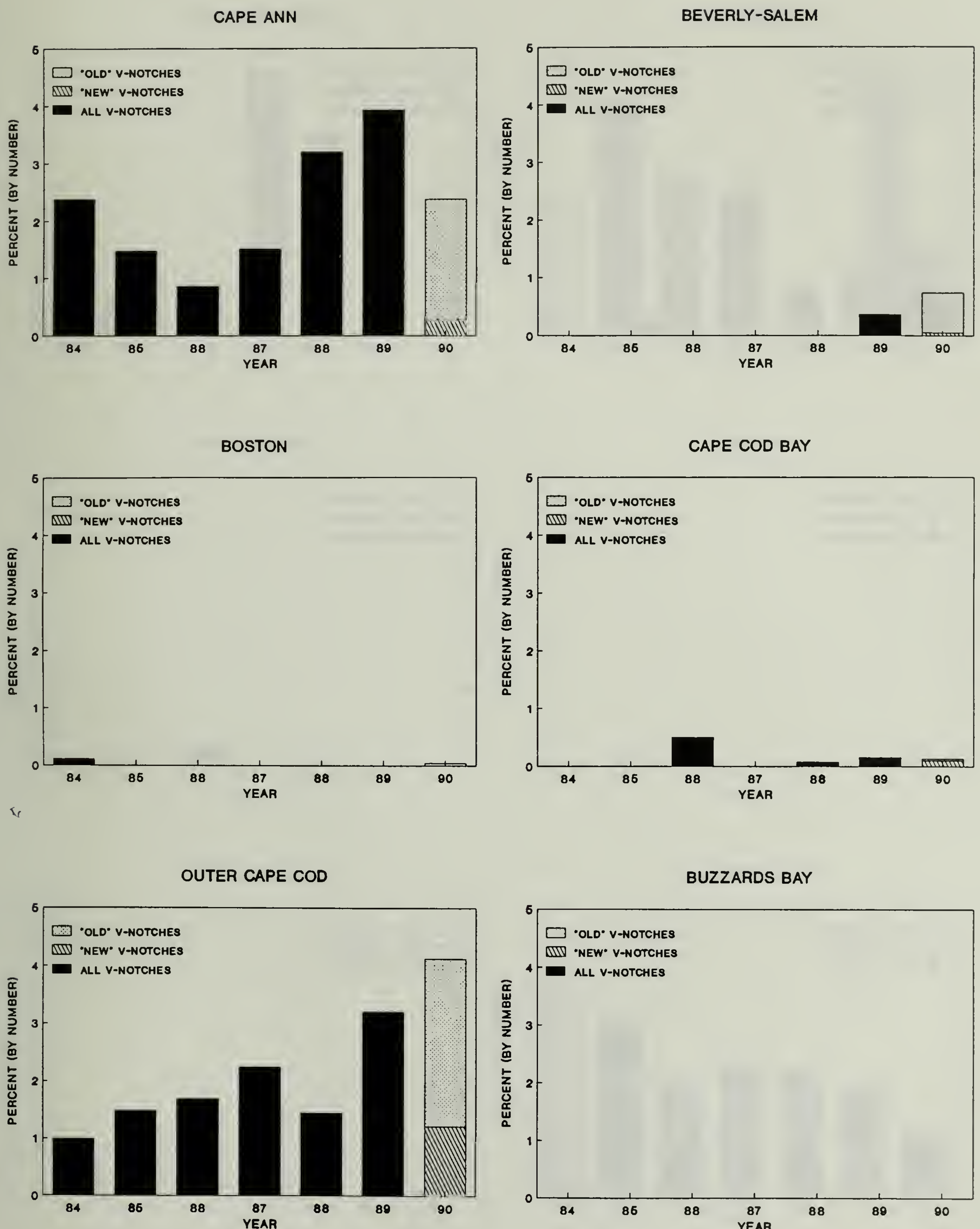


Figure 10A. Percent of marketable American lobster with V-notches by number, Massachusetts coastal regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

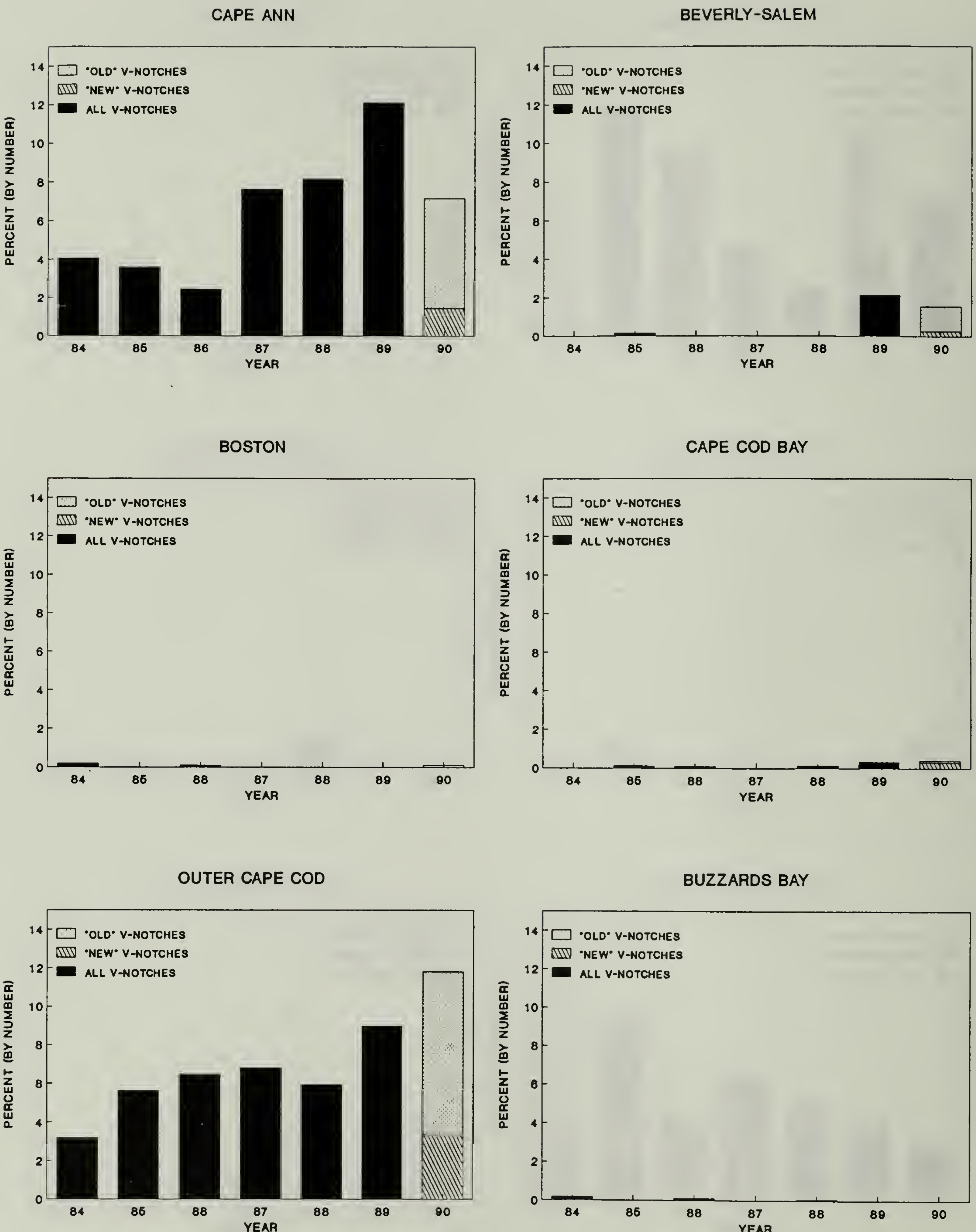


Figure 10B. Percent of legal size female American lobster with V-notches by number, Massachusetts coastal regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

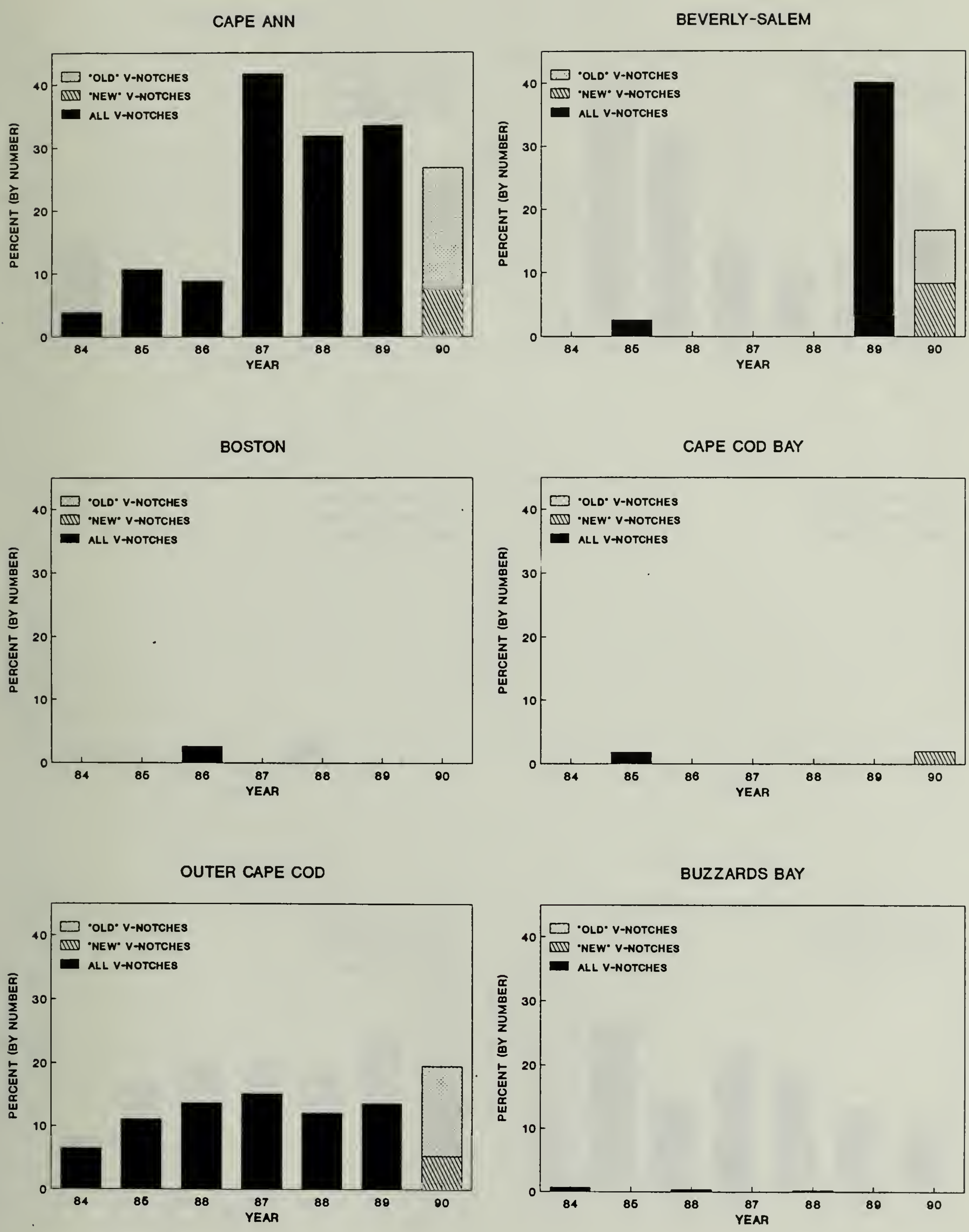


Figure 10C. Percent of legal-sized ovigerous female American lobster with V-notches by number, Massachusetts coastal regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

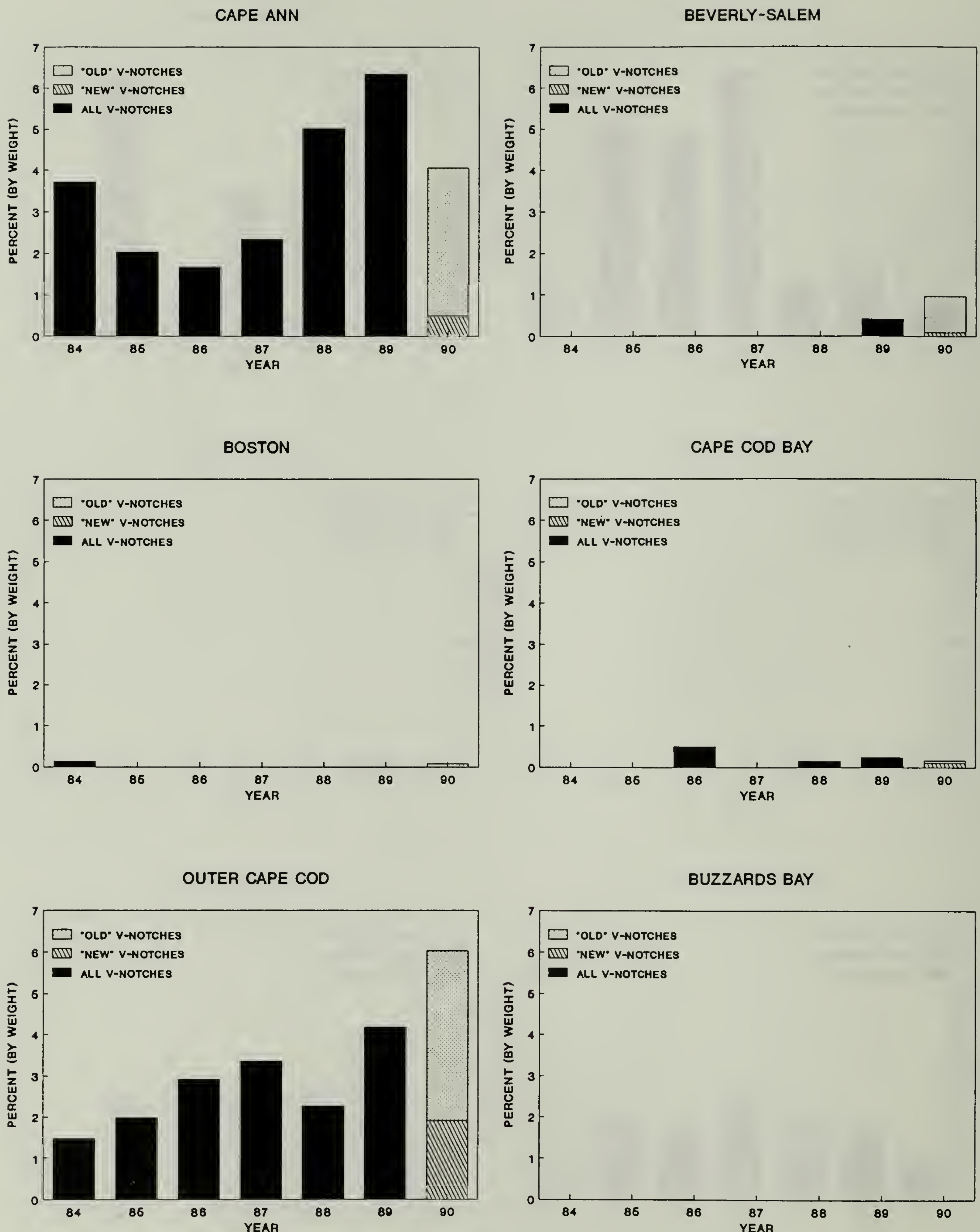


Figure 10D. Percent of marketable American lobster with V-notches by weight, Massachusetts coastal regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

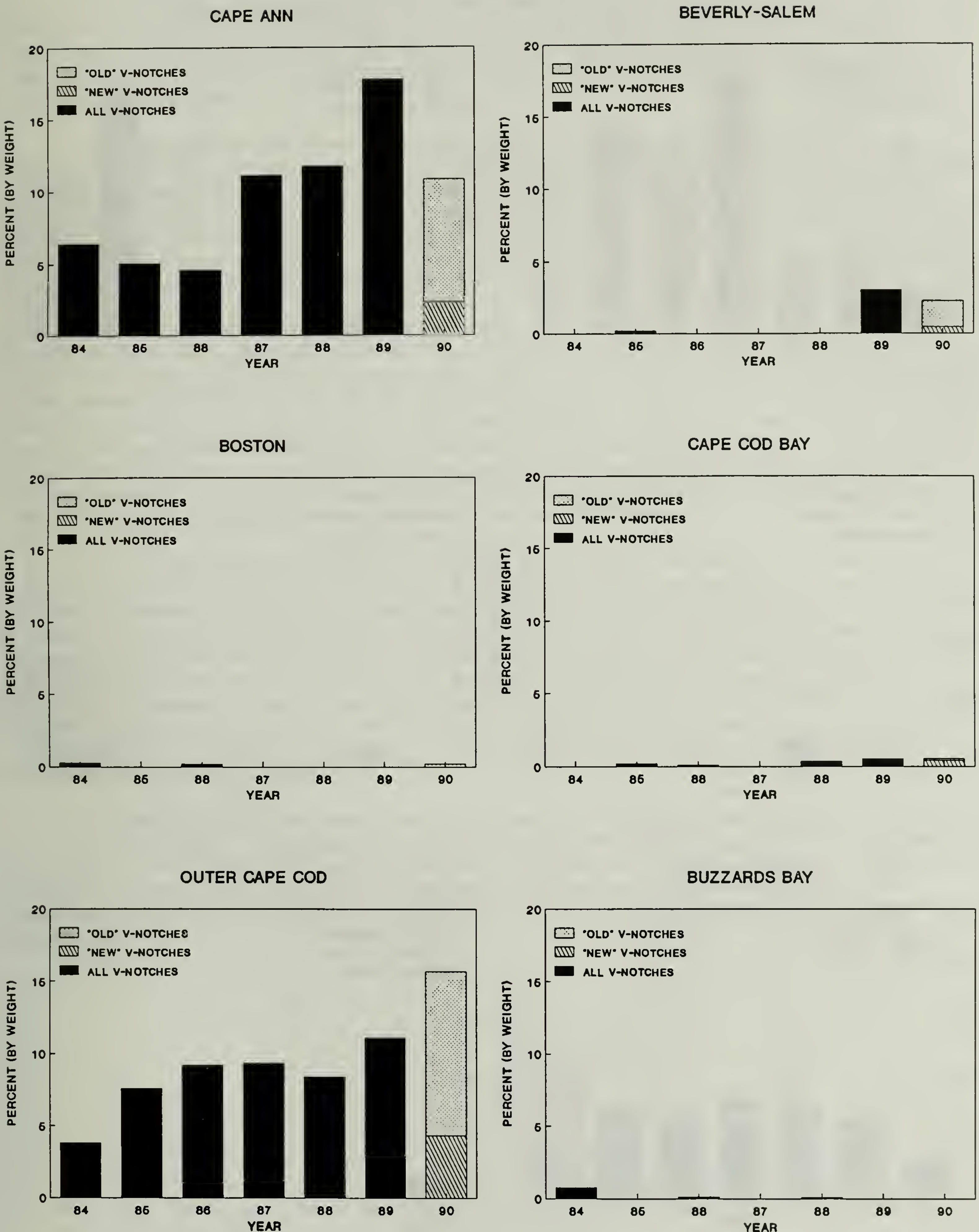


Figure 10E. Percent of legal size female American lobster with V-notches by weight, Massachusetts coastal regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

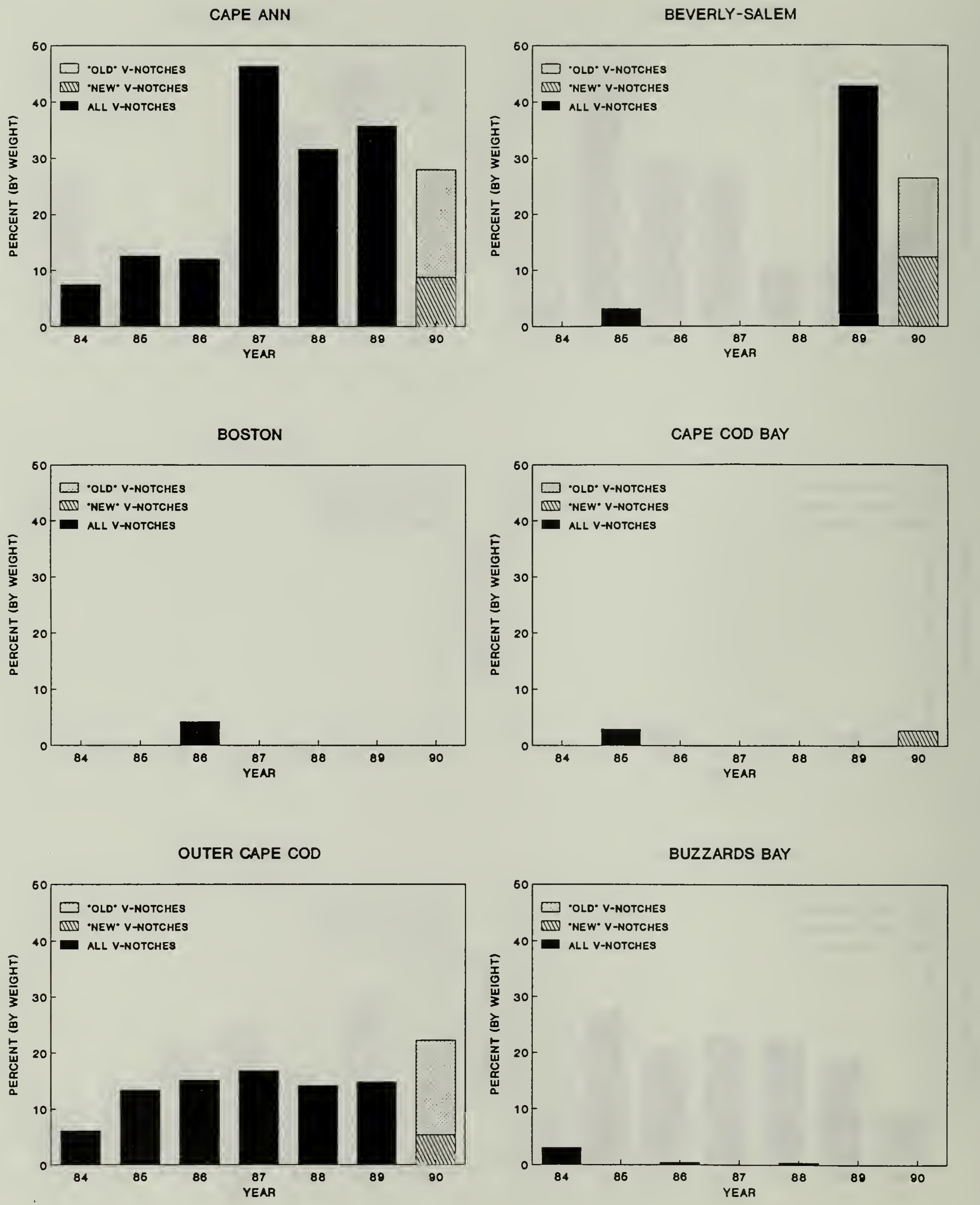


Figure 10F. Percent of legal-sized ovigerous female American lobster with V-notches by weight, coastal Massachusetts regions, 1984-1990. Comparison of percent V-notched by "old" and "new" methods is presented for 1990.

Gauge Increase Assessment

On 1 January, 1988 a five-year gauge increase program was initiated for American lobster. This change was promulgated by the New England Fishery Management Council in cooperation with the lobster-producing states in New England and the Mid-Atlantic. The minimum legal carapace length was raised from 81 mm (3 3/16") to 81.8 mm (3 7/32") in 1988 and to 82.6 mm (3 1/4") on 1 January, 1989. No increase in minimum legal size occurred during 1990.

An approximate 8% short-term loss in number of lobster was predicted for the Massachusetts inshore fishery during the beginning of the first year (1988) of the gauge increase program. This short-term loss was expected to diminish as recruitment from molting adjusted the size frequency. Estrella and Cadrin (1989) reported that the 1988 lobster fishery was not impacted as expected due to excellent recruitment of sublegal lobster into the legal size range. However, an 8% decrease in the catch rate of marketable lobster (by number) was observed in 1989. This may be partly due to expected short-term losses from the second increase compounded by a substantially lower catch in the Cape Cod Bay region which represents a significant proportion of our study area and, therefore, largely affects our coastal catch rate. This decline in catch per unit effort (in number of lobster) occurred uncharacteristically with a 3% increase in total pounds of lobster landed in Massachusetts. The predicted long term adjustment in size distribution of the resource (relative to increases in the minimum size) which is characterized by an increase in yield may have contributed to the disparate increase in total landings. However, during 1990, substantial increases occurred in both the catch rate for marketable lobster and landings. The large catches of juveniles recorded in 1989 no doubt contributed to these increases. The catch rate of sublegal lobster between 1989 and 1990 was relatively stable.

One of the predicted benefits of raising the minimum legal size for American lobster was that growth overfishing would be alleviated by increasing yield per recruit. As the gauge increase program progressed during 1988 and 1989 the size frequency of lobster gradually adjusted to the new gauge dimensions via growth. A shift of the size frequency to larger sizes occurred (Figure 11). Only minor differences were observed between 1989 and 1990 size frequencies. A graphical analysis of 1986-1990 size frequency data, converted to market weight categories, shows the improvement in 1988-1989 data. A slight decline in the chicken category occurred in conjunction with an increased proportion of 1¼ - 1½ lb. and 1½- 3 lb lobster (Figure 12). The relative size of these market categories appeared to stabilize in 1990.

An assessment of changes in the size structure of egg-bearing females was made with catch rates by 10 mm size groups for the years 1986-1990 (Figure 13). An increase in the relative abundance of ovigerous females was apparent in many 1990 size categories. Since the proportion of egg-bearing females to all females increased by only 1%, the increase in catch rates of eggers was likely caused by the overall increase in lobster abundance.

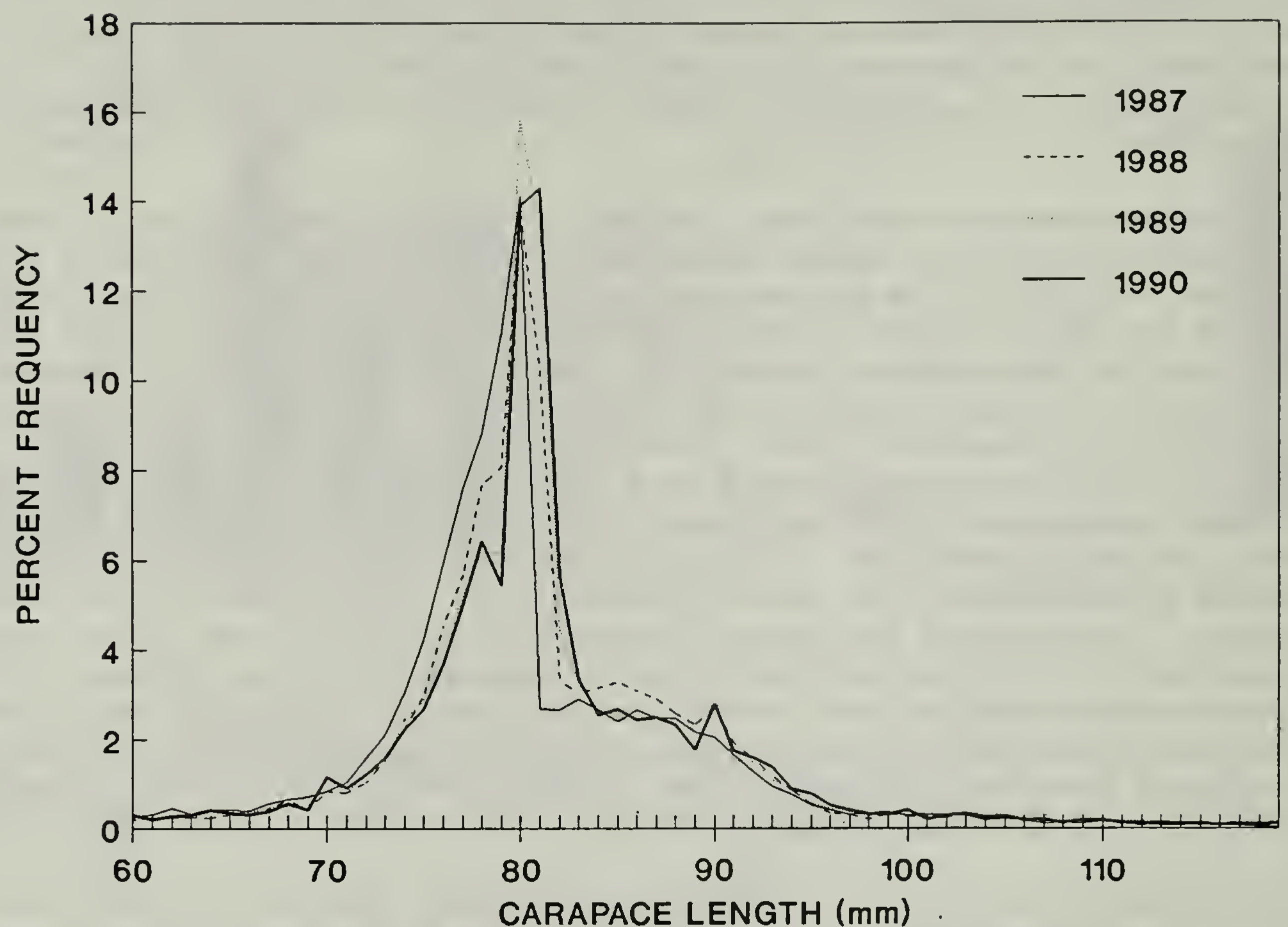


Figure 11. American lobster carapace length frequency from commercial lobster trap sampling, Massachusetts coastal waters, 1987-1990.

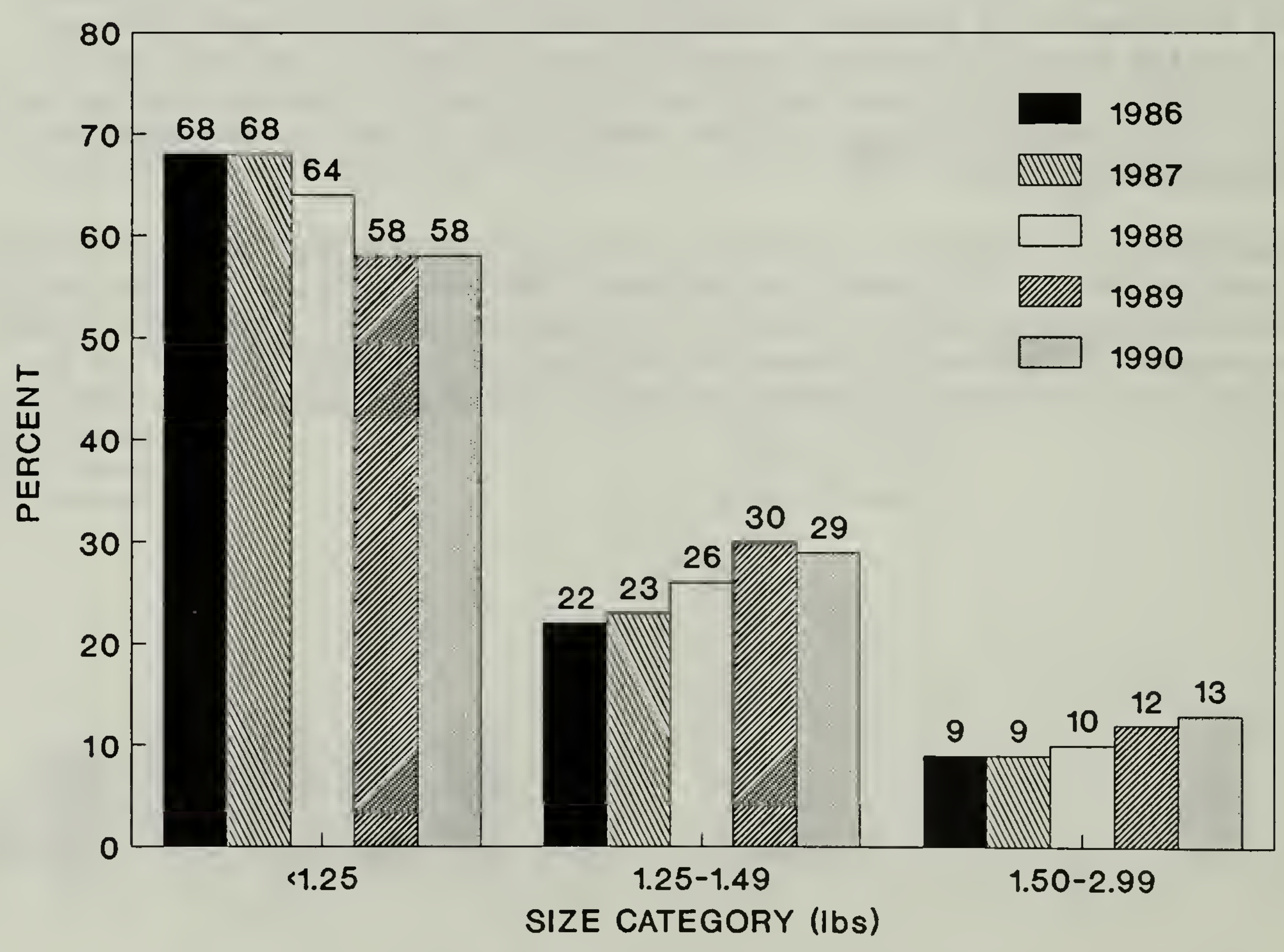
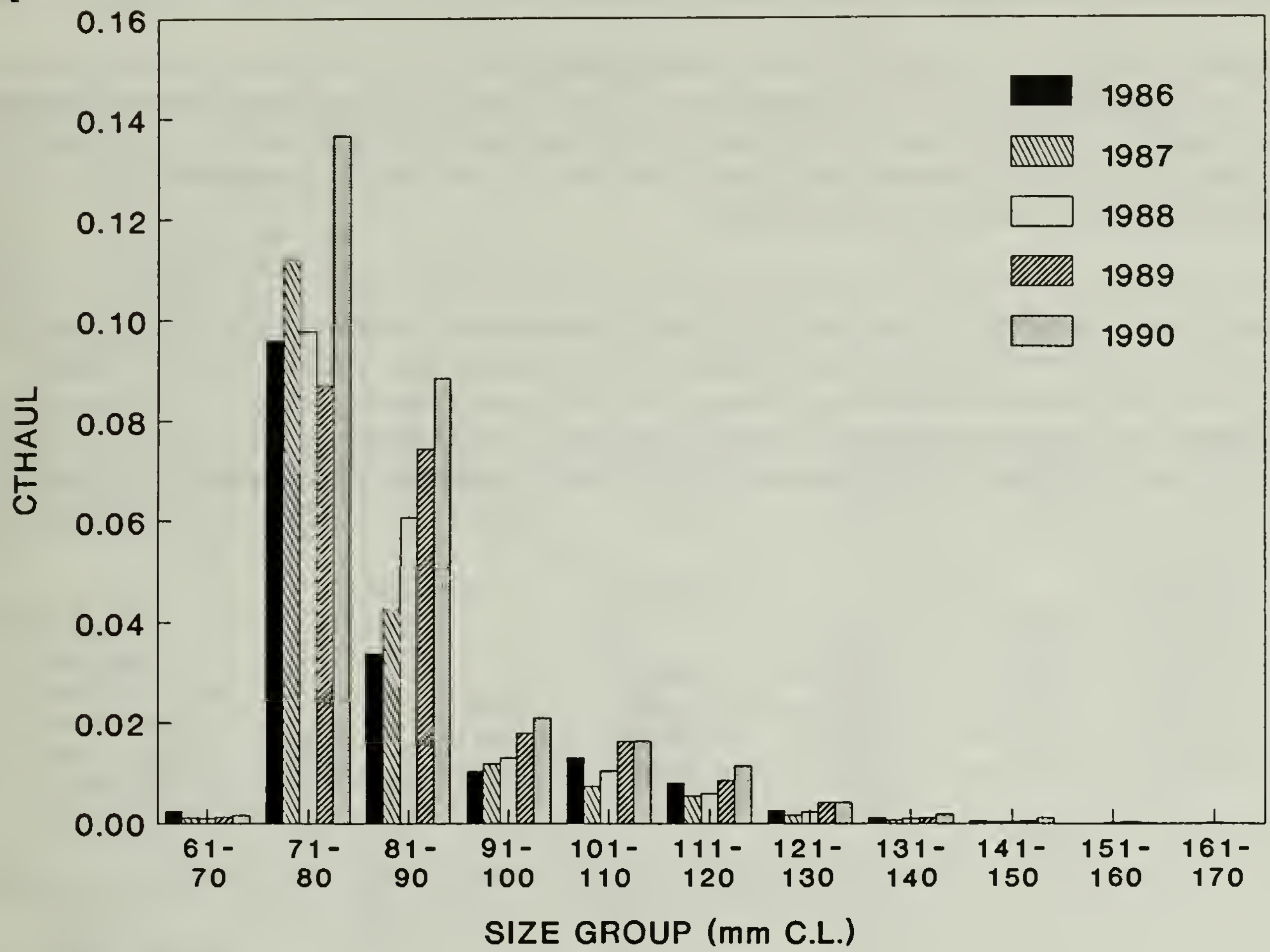


Figure 12. Percent of marketable lobster by market weight categories from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1990.

A



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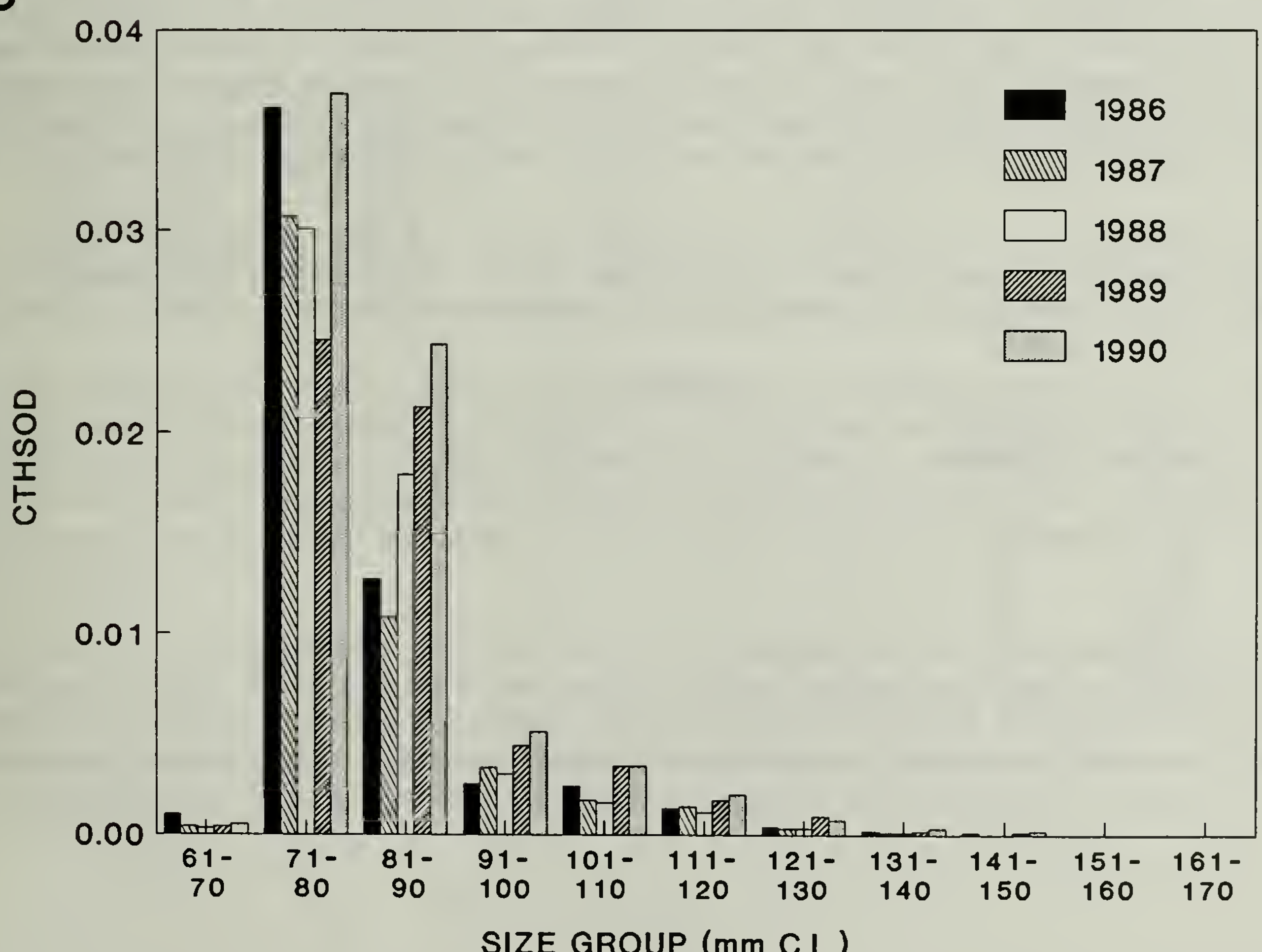


Figure 13. Catch per trap haul (A) and catch per trap haul set-over-day (B) of ovigerous female American lobster by 10 mm size groups, from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1990.

Standardization of Shell Disease Sampling

A total 4,791 lobster were sampled for shell disease in 1989 and 4,225 in 1990 through commercial sea sampling off Massachusetts.

Pearson's r correlated coefficients were calculated for 1989 data. Shell disease prevalence was correlated with all parameters tested including carapace length, shell hardness, sex and ovigerous condition, anatomical location of symptoms, region and month (Table 1). Many of these "independent" variables were also intercorrelated due to their seasonal (monthly) and regional variability.

Table 1. Pearson's r correlation matrix for variables tested in association with shell disease prevalence of American lobster, Massachusetts coastal waters, 1989.

	Shell Disease (SD)	Carapace Length (CL)	Shell Hardness (SH)	Sex & Ovig. Condition (SO)	Anatomical Location (AL)	Region (R)	Month (M)
SD	1.0000						
CL	0.0531**	1.0000					
SH	0.2052**	-0.0349	1.0000				
SO	-0.2542**	-0.1073**	-0.1215**	1.0000			
AL	0.7086**	0.0418*	0.1495**	-0.1485**	1.0000		
R	0.2775**	0.0966**	-0.0482**	-0.1702**	0.1700**	1.0000	
M	0.0937**	0.0791**	-0.1851**	-0.0318	0.0615**	-0.0548**	1.0000

* = P ≤ 0.01; ** = P ≤ 0.001

The coastwide mean CL of lobster sampled was significantly greater during September through November than in earlier months (P = 0.05; Table 2). Lobster from the outer Cape Cod region averaged 92.9 mm CL. This was significantly larger than the other regions which ranged from 78.6 to 82.1 mm CL. Although samples from the latter regions exhibited similar means, significant differences were found among them (Table 3). Mean sizes of lobster sampled by sex and condition (shell hardness, ovigerous) within each region also exhibited variability (Table 4) which warranted standardization in disease analyses.

Table 2. Mean carapace length (mm) of American lobster by month with pairs of months significantly different at alpha = 0.05 (*), Massachusetts coastal waters, 1989.

		Month						
Mean	Month	6	5	8	7	9	10	11
81.3	6							
81.3	5							
81.4	8							
81.9	7							
82.6	9	*	*	*				
82.8	10	*	*	*				
84.0	11	*	*	*	*	*	*	

Table 3. Mean carapace length (mm) of American lobster by region with pairs of regions significantly different of alpha = 0.05 (*), Massachusetts coastal waters, 1989.

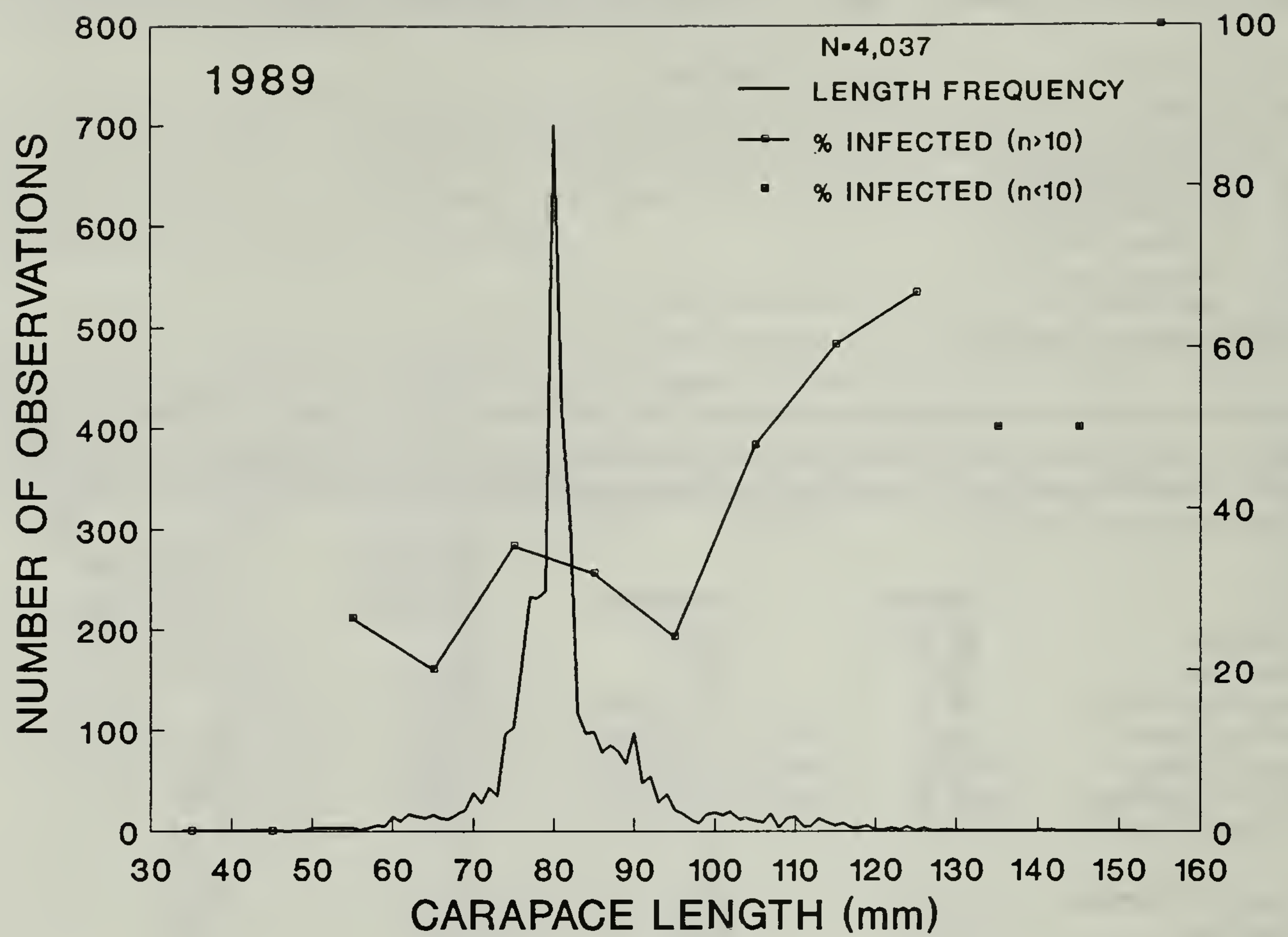
Mean	Region	2	4	6	3	1	5
78.6	Beverly-Salem (2)						
79.8	Cape Cod Bay (4)	*					
80.1	Buzzards Bay (6)	*					
80.6	Boston Harbor (3)	*	*				
82.1	Cape Ann (1)	*	*	*	*		
97.9	Outer Cape Cod (5)	*	*	*	*	*	

Table 4. Mean carapace lengths of American lobster by sex and ovigerous condition for all lobster, hardshelled, and newshelled lobster sampled for shell disease, Massachusetts coastal waters, 1989.

	Males	Females	Nonovig. Females	Ovigerous Females
All Lobster	82.0	82.3	81.1	89.1
Cape Ann	82.0	82.2	81.7	95.8
Beverly-Salem	78.5	78.6	78.6	----
Boston Harbor	81.5	79.9	79.7	86.6
Cape Cod Bay	79.9	79.7	79.4	87.5
Outer Cape Cod	95.9	99.5	94.5	107.1
Buzzards Bay	79.4	80.4	79.9	81.4
Hardshelled Lobster	81.6	82.3	80.9	89.1
Cape Ann	82.0	82.2	81.7	95.8
Beverly-Salem	78.0	78.5	78.5	----
Boston Harbor	78.4	78.9	78.4	86.6
Cape Cod Bay	79.6	79.5	79.2	87.5
Outer Cape Cod	96.0	99.5	94.0	107.1
Buzzards Bay	79.3	80.3	79.6	81.4
Newshelled Lobster	83.8	82.1	82.1	----
Cape Ann	90.0	----	----	----
Beverly-Salem	86.1	84.3	84.3	----
Boston Harbor	83.7	81.1	81.1	----
Cape Cod Bay	82.8	83.3	83.3	----
Outer Cape Cod	94.6	99.1	99.1	----
Buzzards Bay	79.5	81.1	81.1	----

The positive correlation between shell disease and lobster size (Table 1) was strong for hardshelled lobster ($r = 0.0679$, $P \leq 0.001$) and weak for newshelled lobster ($r = -0.0144$, $P = 0.692$. This relationship was supported by both 1989 and 1990 data (Figures 14 and 15). Subsequent analyses were conducted on only hardshelled lobster in the 71-90 mm CL range. This size range is most often available to commercial traps and represents the bulk of the samples collected.

Analyses by region for 1989 and 1990 data indicated that Buzzards Bay lobster exhibited more shell disease than other regions. The percent of females infected (including ovigerous lobster) was consistently higher than males ($P < 0.0001$ in both years, Figure 16). Non-ovigerous females also exhibited a disease prevalence which was generally higher than that of males but not significantly different ($P = 0.0978$ in 1989 and $P = 0.0007$ in 1990).



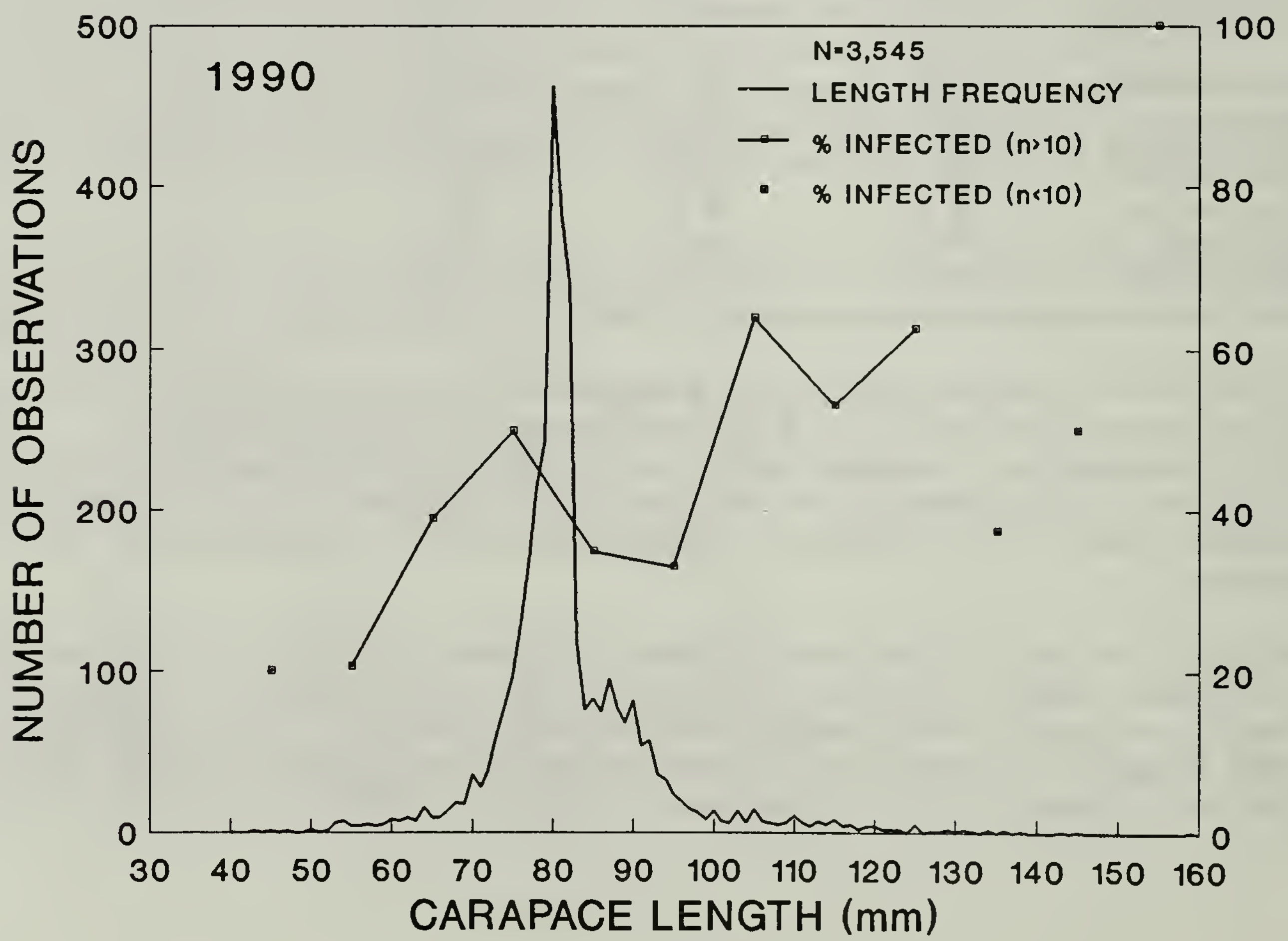
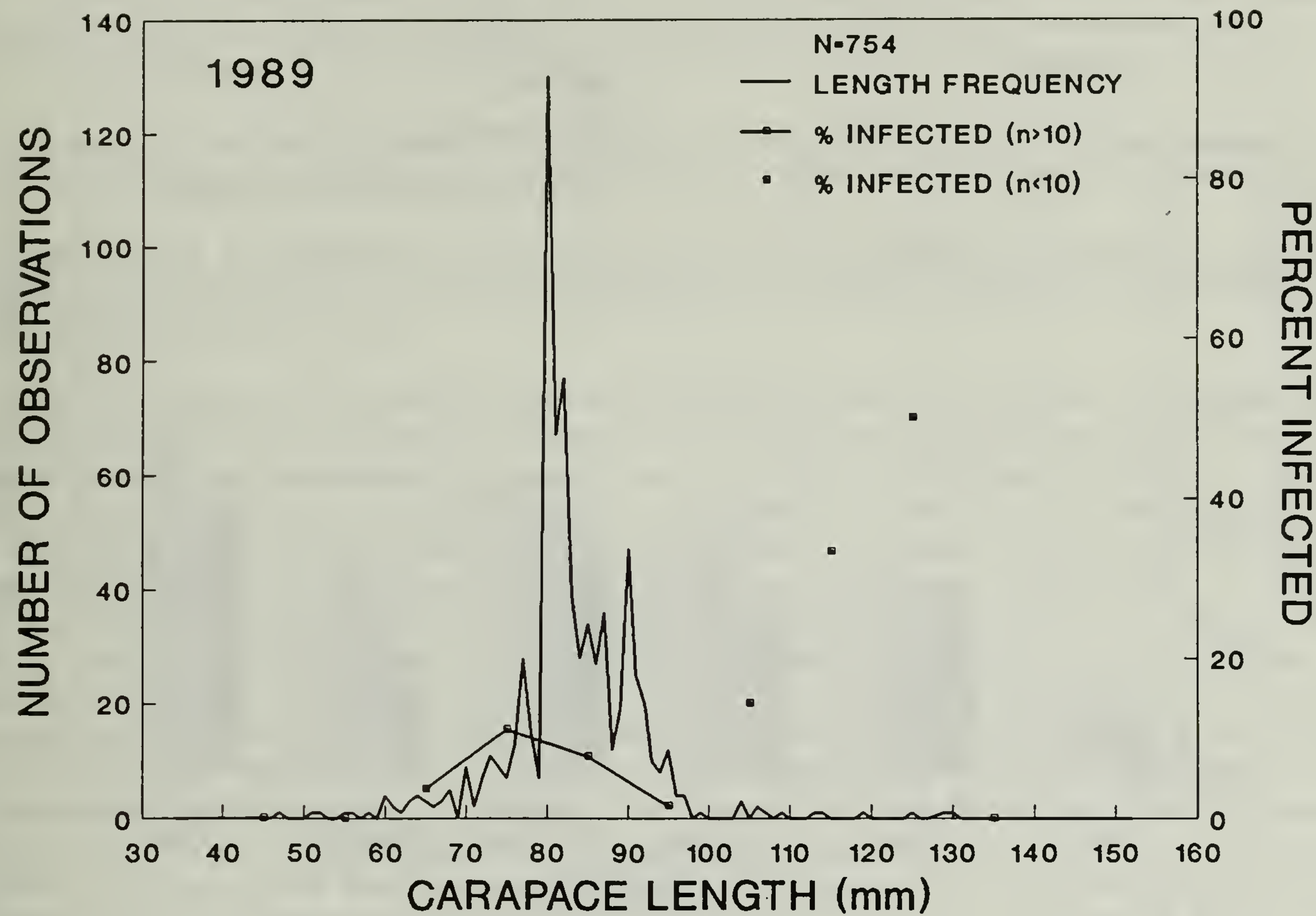


Figure 14. Relationship between shell disease in hard-shelled American lobster and lobster carapace length plotted against length frequency of samples, Massachusetts coastal waters, 1989-1990.



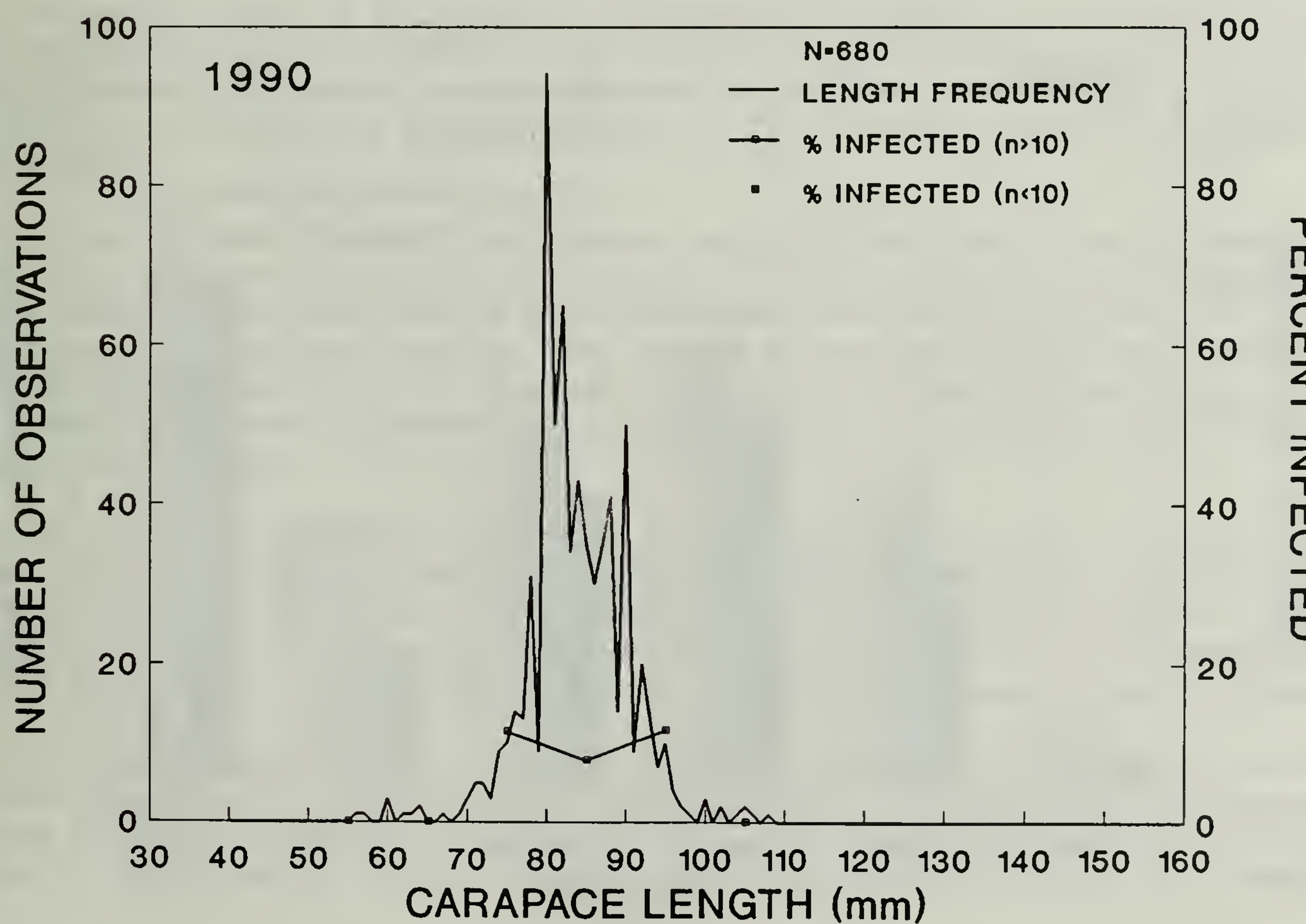


Figure 5. Relationship between shell disease in new-shelled American lobster and lobster carapace length, plotted against length frequency of samples, Massachusetts coastal water, 1989-1990.

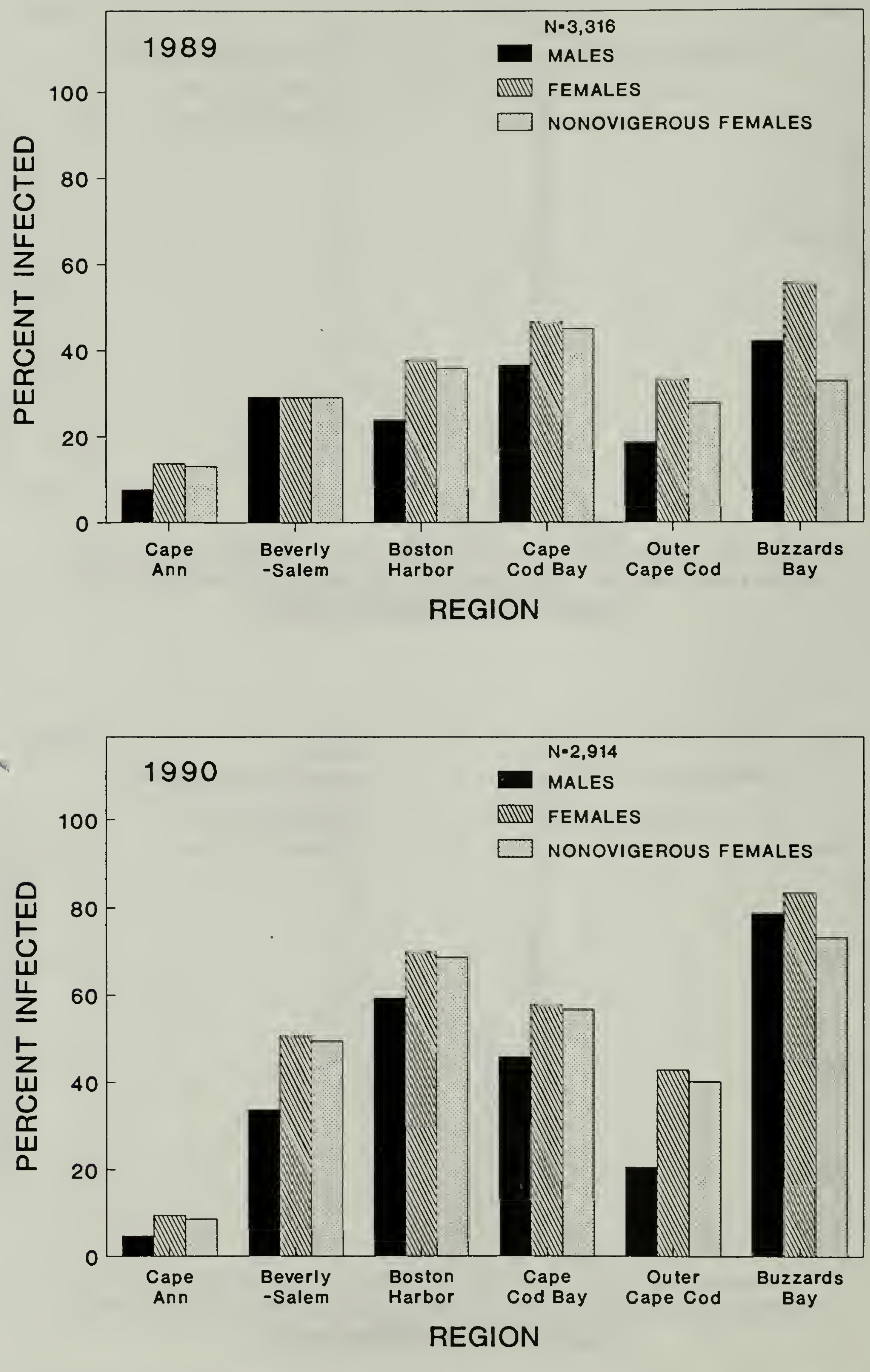


Figure 16. Shell disease in hardshelled American lobster (71-90 mm CL) by sex and ovigerous condition from six Massachusetts coastal regions, 1989-1990.

Ovigerous (egg-bearing) females in the 71-90 mm CL category exhibited a greater prevalence of symptoms, 83.9 % in 1989 and 87.6% in 1990, than similar sized non-ovigerous females, 29.4 % in 1989 and 41.6% in 1990. ($P < 0.0001$) or males 26.6 % in 1989 and 35.1% in 1990 ($P < 0.0001$ in both years). Although brown ovigerous females were more symptomatic than green ovigerous females (Figure 17), no significant difference was observed ($P = 0.2570$ in 1989 and $P = 0.3764$ in 1990).

An analysis of shell disease on hardshelled lobster by 10 mm groupings and severity indicated a tendency for ulceration to be more prevalent with larger size groups (Figure 18).

Analyses of hardshelled lobster by severity and anatomical location revealed that most shell disease was found on claws (generally the ventral side) followed by the tail, carapace, and legs (Figure 19).

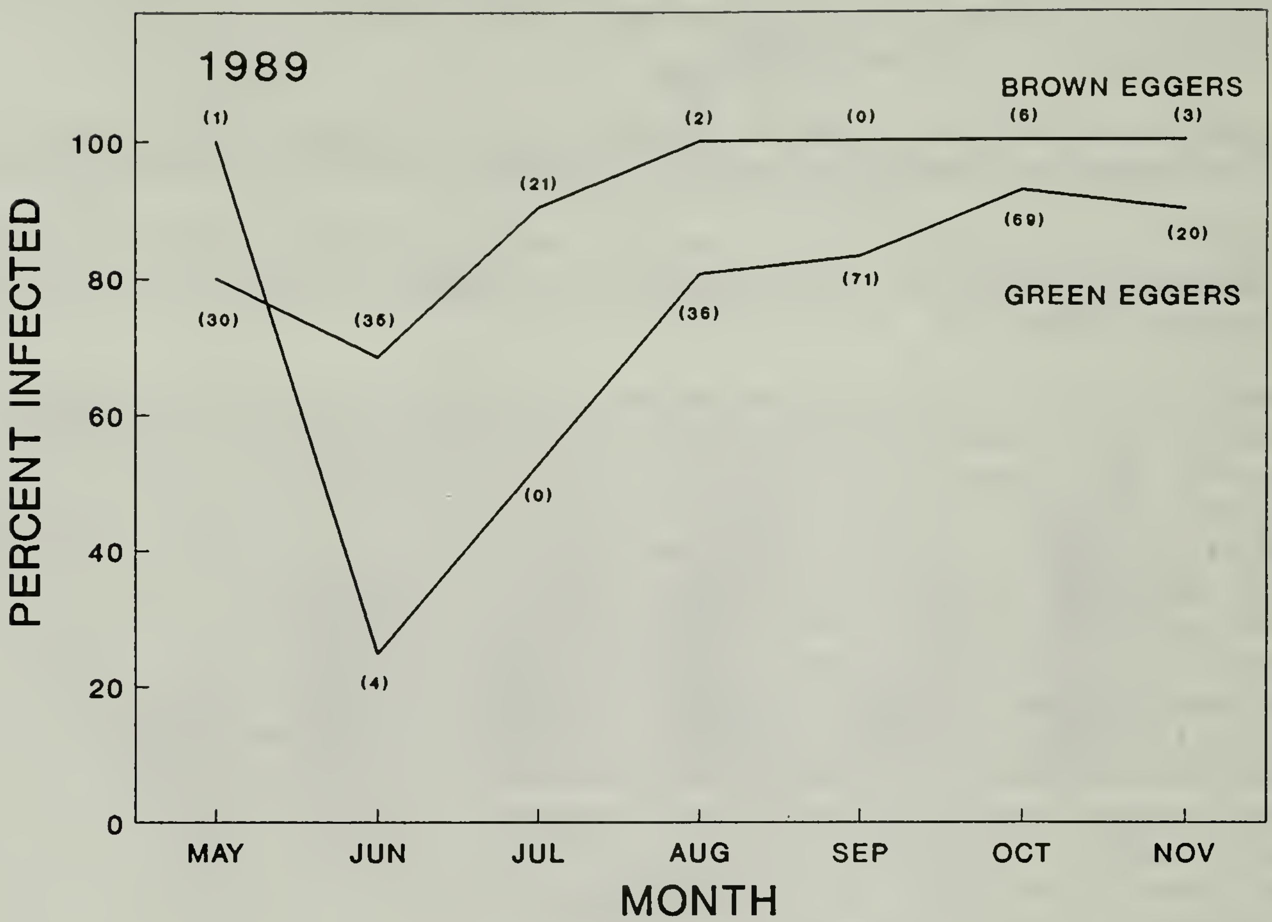
Lobster size, sex, and ovigerous condition exhibited the greatest influence on shell disease prevalence. The increase in disease prevalence with lobster size indicates a relationship with environmental exposure time. Lobster which measure from 71-98 mm carapace length may molt 0-2 times annually (Hughes and Matthiessen 1962). Smaller lobster molt at a greater frequency and are more likely to shed their shells before chitin deterioration becomes severe enough to effect necrosis of underlying tissue. Hardshelled lobster had a higher infection rate than newshelled lobster because their shells were exposed to the environment for a longer period of time. Ovigerous females exhibited the greatest prevalence of shell disease because molting is delayed until after hatching and their shells are thus retained for a longer period. However, non-ovigerous females were also generally more symptomatic than males. Some spent egg-bearing females may have been included in the samples analyzed but the comparatively slower growth of females when sexually mature, i.e. reduced molt frequency from the 2-year ovarian cycle, is likely responsible. Estrella and McKiernan (1989) defined the size at 50% maturity for female American lobster in Massachusetts coastal waters as 76 mm CL in Buzzards Bay, 87 mm CL in Cape Cod Bay and Boston Harbor, 90 mm CL off Cape Ann, and 97 mm CL off outer Cape Cod.

The large number of specimens with symptoms of pitting, i.e. infected shell pores, affirms the ever-present availability of the causative agent(s) and the need to screen samples adequately to develop accurate disease indices. The tendency for ulceration to occur with greater frequency in large lobster was due to their comparatively longer shell exposure times.

Green ovigerous females have a shorter exposure time than brown ovigerous females. They may extrude eggs from several to 10 months after molting whereas brown ovigerous females may have gone up to an additional year longer than that period before egg hatching and subsequent molting. The lack of a statistically significant difference in shell disease prevalence between green and brown ovigerous females may be due to the lack of fall samples of brown ovigerous females and the lack of spring samples of green ovigerous females (Figure 17).

The high frequency of symptoms on the ventral surface of the major claws may be the result of regular contact of this anatomical area with the sediment. Abrasion of the shell pores there probably enhances infection. Young and Pearce (1975) made similar observations on lobster and rock crabs (*Cancer irroratus*) in heavily polluted areas of the New York Bight. They stated that the tips of the walking legs were often symptomatic.

This methodology was developed as a standard approach to monitoring trends in shell disease prevalence in Massachusetts coastal waters. Accordingly, the comparability of these data to previous studies is not possible due to differences among them in lobster size distribution, molt stage, sex ratio, ovigerous condition, sampling location, and respective



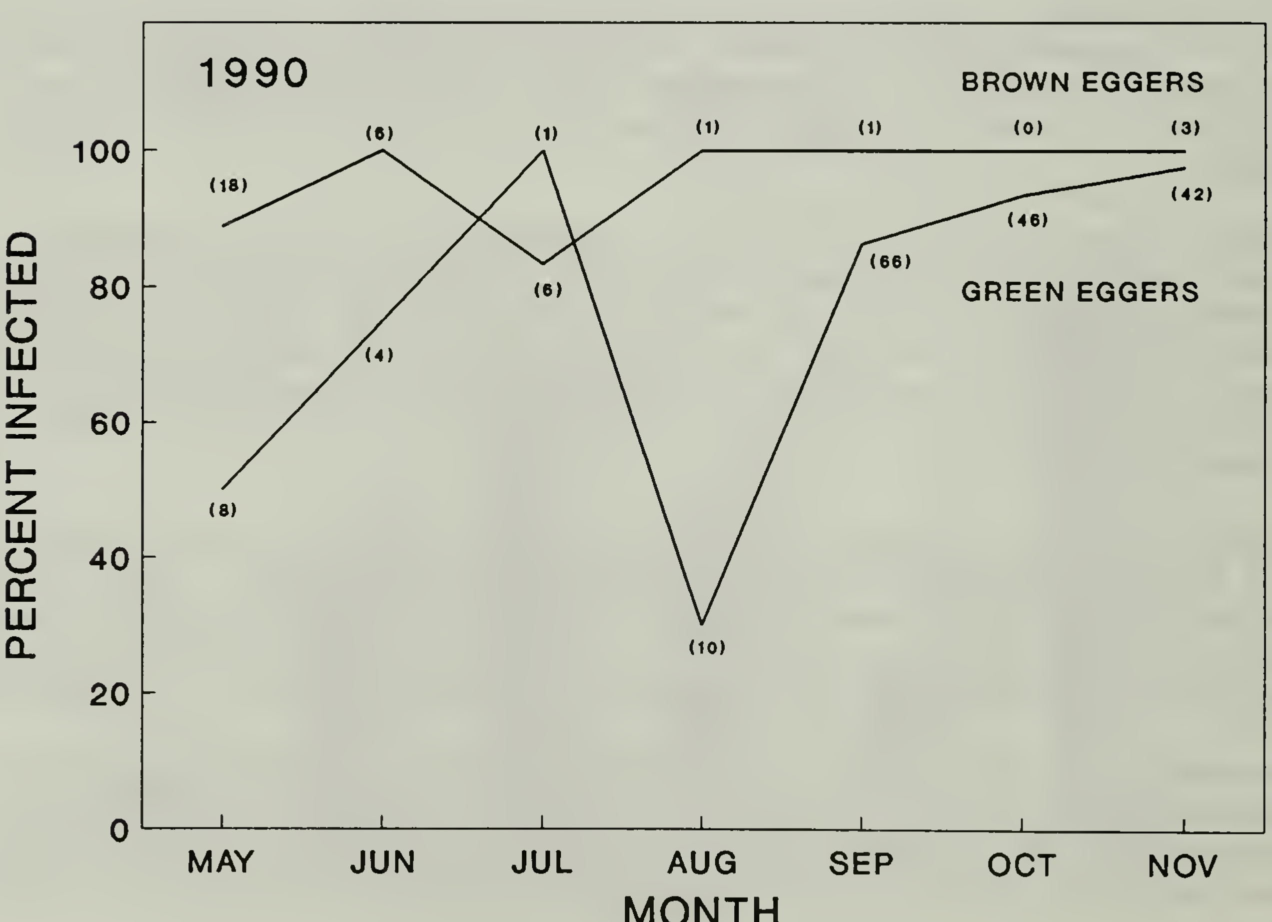
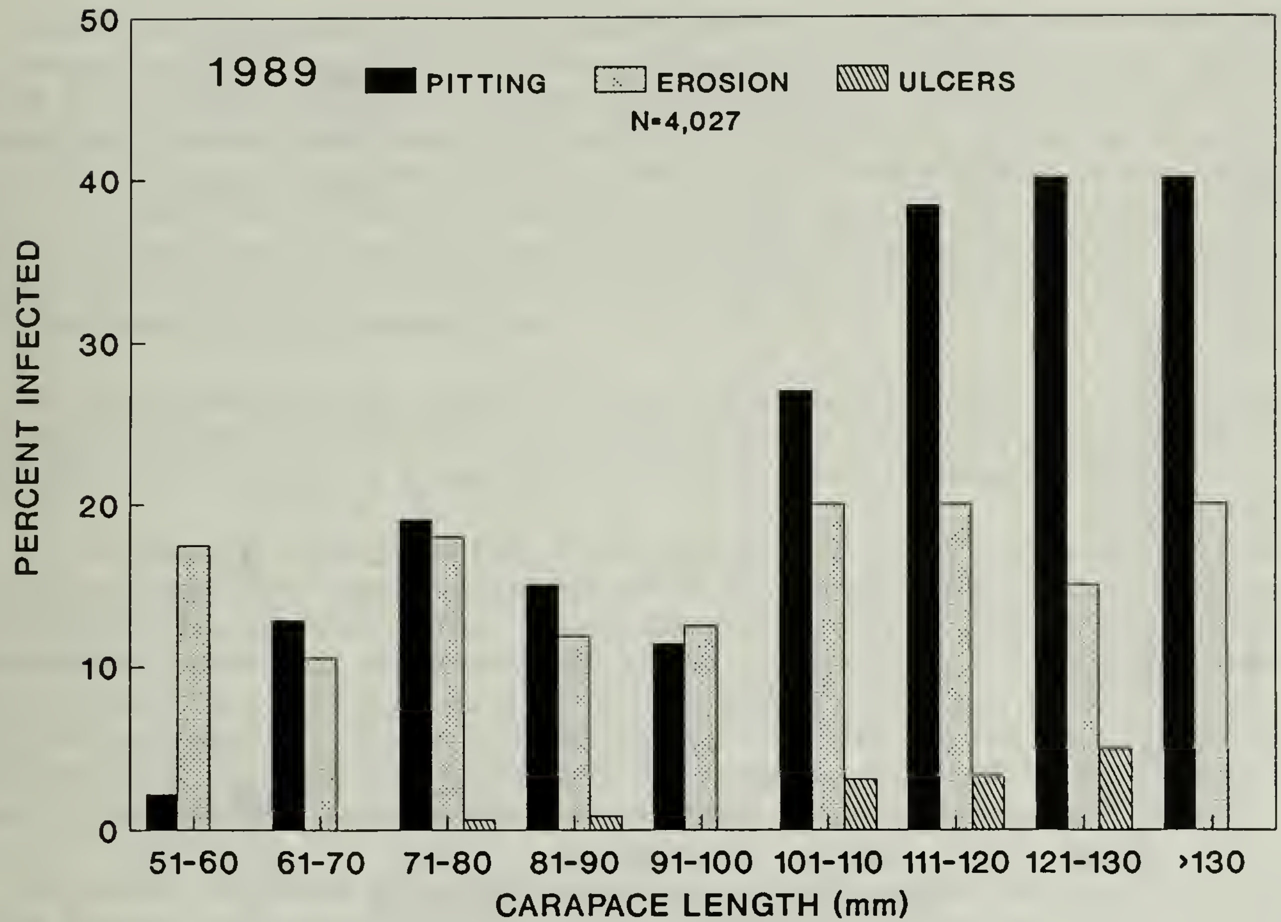


Figure 17. Shell disease in brown (developing eggs) and green (newly extruded eggs) egg-bearing American lobster females by month, Massachusetts coastal waters, 1989-1990.



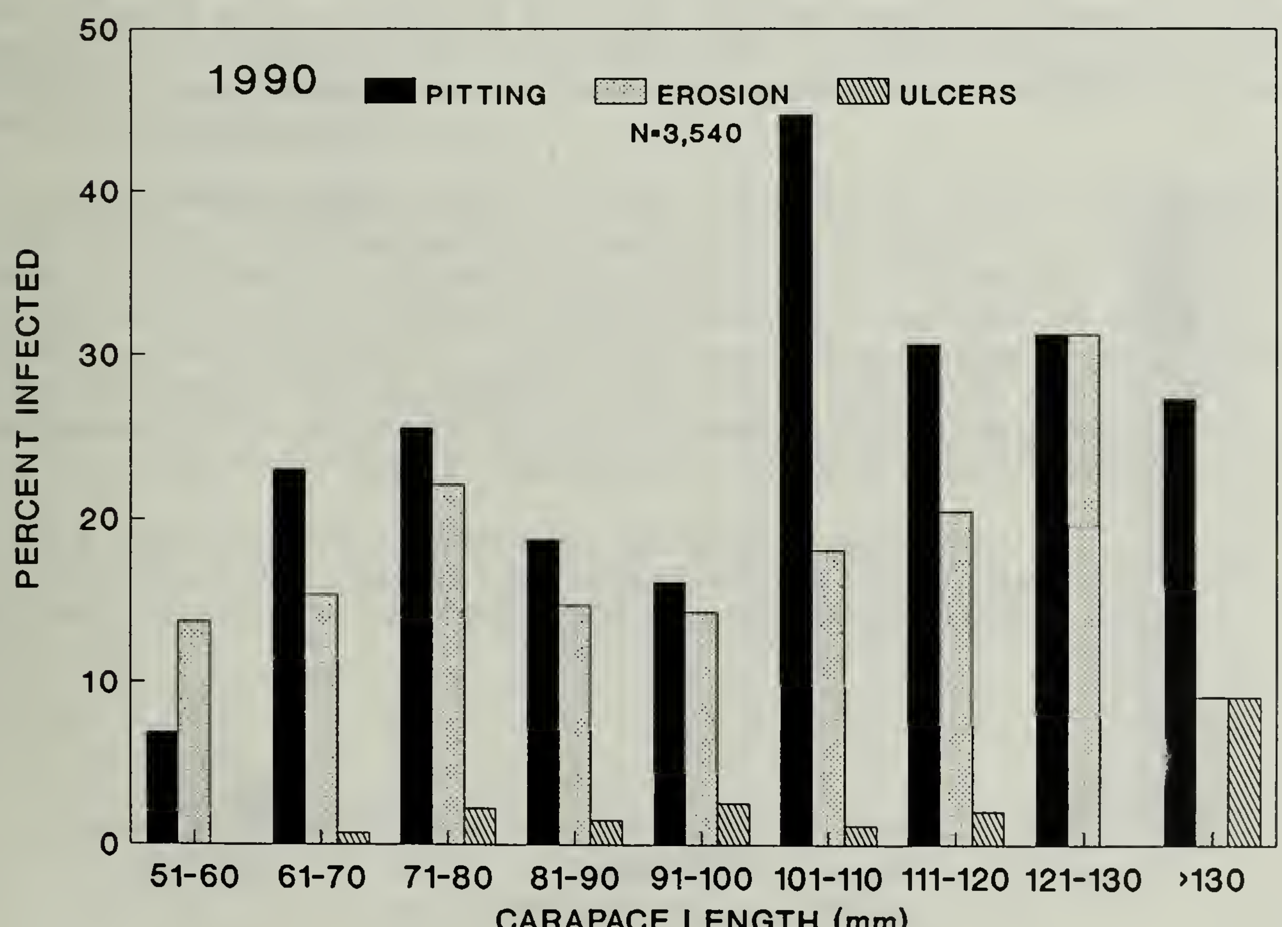


Figure 18. Shell disease in hard-shelled American lobster by 10 mm CL groupings and severity, Massachusetts coastal waters, 1989-1990.

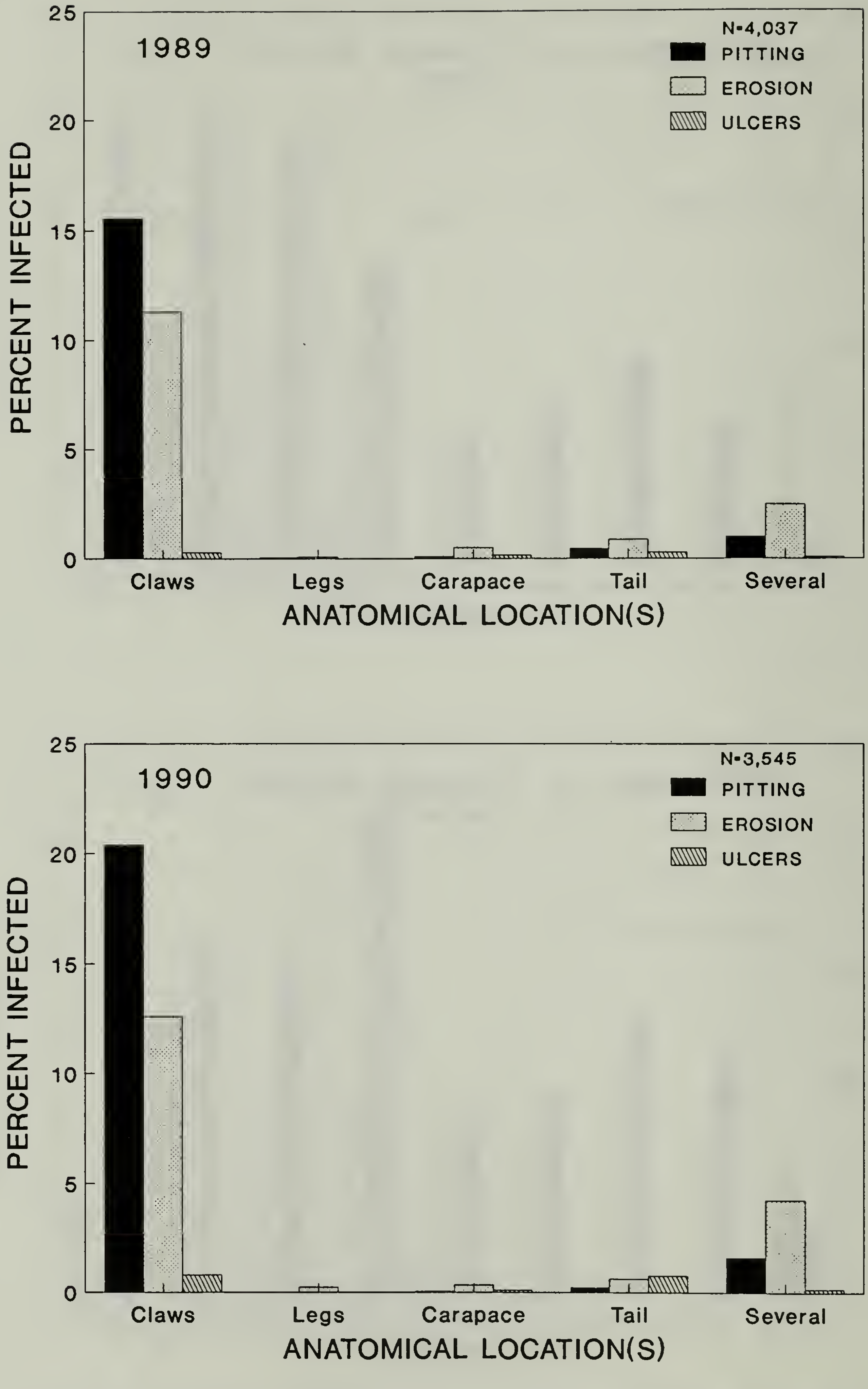


Figure 19. Shell disease in hard-shelled American lobster by severity and anatomical location, Massachusetts coastal waters, 1989-1990.

sample sizes. Also, the inclusion of symptoms at the pore level in gross evaluations has raised prevalence estimates from those previously calculated and warrants reinitiation of data time series.

Standardization should improve prevalence estimates relative to concerns about environmental conditions which can stress crustacean health and enhance shell disease. Although the symptoms of shell erosion and melanization of diseased tissue in crustaceans are ubiquitous, high prevalences have been reported near ocean disposal sites (Gopalan and Young 1975; Young and Pearce 1975; Bodammer and Sawyer 1981; Sawyer 1982; Sawyer et al. 1983). In 1988-1989, a joint NOAA/EPA working group made a detailed examination of available information on shell disease in crustaceans from the New York Bight and elsewhere (Sindermann et al. 1989) and concluded that evidence exists for an association of shell disease with habitat degradation.

Previous observations of shell disease in Massachusetts coastal waters (Estrella 1984) indicated an elevated prevalence in Buzzards Bay. Although the data are not directly comparable, this observation is consistent with results of the present study.

Environmental conditions may be responsible. Periodic outbreaks of shell disease in Nova Scotian and Maine coastal impoundments have historically impacted lobster imported into Massachusetts and other states. Complaints have been voiced by local lobster dealers of unaesthetic appearance, weakness, and enhanced mortality among these imports. Heavy organic loading and poor water quality in impoundments, which allow bacteria to flourish, appear to be responsible. Similar conditions have occurred in the wild as a result of marine disposal practices. Sindermann (1989) and Sindermann et al. (1989) summarize published accounts of shell disease prevalence in the vicinity of degraded habitats.

The water exchange rate and turbidity at sampling sites are possible factors affecting disease incidence, Buzzards Bay is a comparatively closed, shallow embayment exhibiting poor circulation (Gilbert et al. 1973) and subsequently warmer bottom temperatures during summer months (Colton and Stoddard 1973). These conditions may promote and maintain bacterial growth. Buzzards Bay waters consistently contain high levels of dissolved solids (Gilbert et al. 1973). Stormy conditions apparently cause resuspension of bottom sediments. In contrast, other regions sampled, with the exception of Boston Harbor, are generally characterized by relatively open water with a greater depth range and cooler water temperatures.

Nevertheless, the establishing of cause and effect is complicated by the potential stress from industrial contaminants such as PCB's, heavy metals, and hydrocarbons which have been found throughout Buzzards Bay (Gilbert et al. 1973) with the highest levels observed in the New Bedford Harbor region (Ellis et al., unpublished manuscript 1977; Kolek and Ceurvels 1981; Weaver 1984). The New Bedford Harbor area is also heavily polluted with domestic sewage (MDEQE, unpublished laboratory results, 1983). However, such pollutants are not limited to this area of Massachusetts coastal waters and occur throughout Massachusetts Bay and Cape Cod Bay (Gilbert et al. 1976; Boehm 1984).

Such conditions provide extensive opportunity for future study of the effects of pollutants. A standardized approach to data acquisition and analysis, as outlined above, should be helpful in disease assessments.

The Effect of Temperature on the Massachusetts Lobster Fishery.

Coastal Massachusetts lobster catch rates generated from commercial sea sampling (Appendix tables) were significantly autocorrelated. Thus, simple regression analysis can not be used to model the relationship between temperature and 1981-1990 sea sampling statistics, because autocorrelation invalidates the assumption of independent samples. Autoregressive analyses (Box and Jenkins 1976) generally require a longer time series than is provided by the ten-year time series of the Massachusetts sea sampling program. Alternatively, annual landings (lbs) and catch per pot from Massachusetts coastal waters as reported by inshore fishermen from 1922 to 1989 (Figure 20) were used in transfer function analysis with temperature.

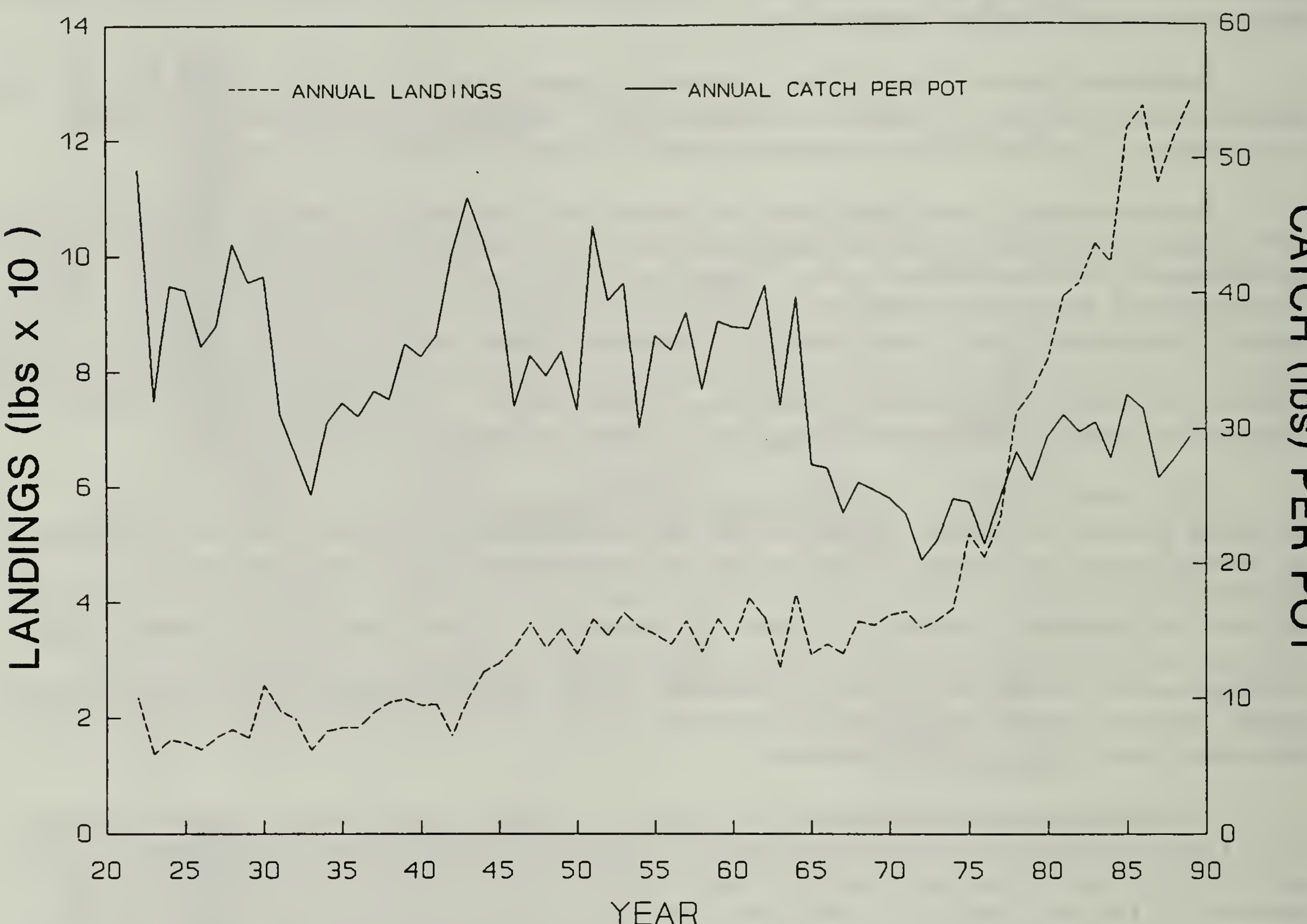


Figure 20. Annual reported lobster landings and catch per pot from coastal Massachusetts waters, 1945-1989 (data from Estrella and McKiernan 1989).

Daily sea surface temperature records were obtained from the NOAA/National Ocean Survey, Woods Hole station (1945-1989) and Boston Harbor station (1922-1989); annual means for both series are plotted in Figure 21. For the years 1971 and 1972 there were no temperatures recorded at the Boston Harbor station. This gap in the time series was filled using temperature data collated by the U.S. Environmental Protection Agency from various sampling efforts in Boston harbor. Temperatures for minor data gaps in other years (average of 3.68 days per month had no temperature recorded) were interpolated linearly.

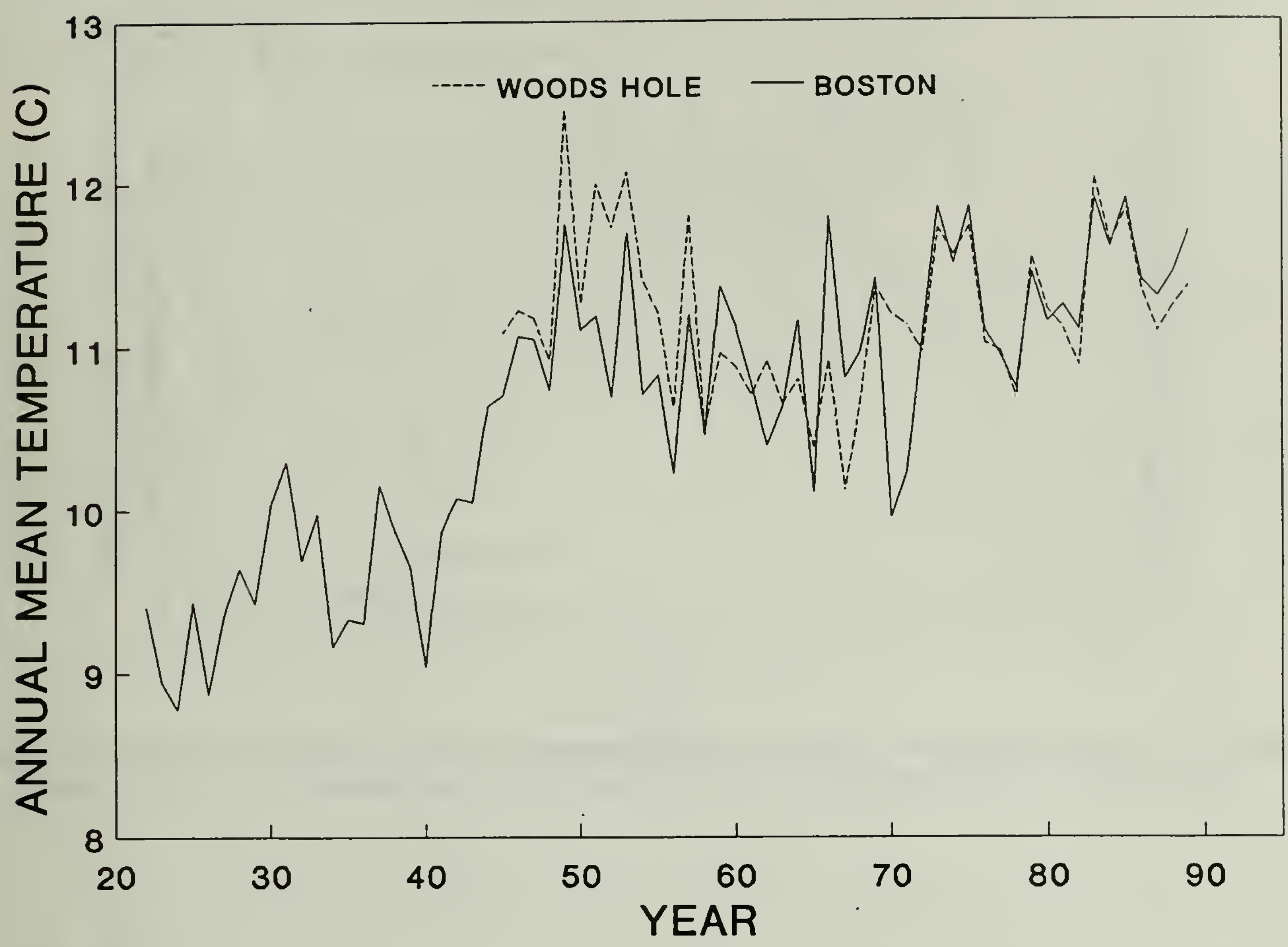


Figure 21. Annual mean sea surface temperature from NOAA/NOS Woods Hole and Boston Harbor stations.

To estimate annual and seasonal variation in the period of lobster activity, "warming degree days" (WD, defined as total degrees greater than 5 °C for each daily temperature; $WD=\Sigma[(y_i-5)+|y_i-5|]/2$, where y_i=daily temperature in °C) were calculated (Figures 22 and 24). A threshold of 5 °C was chosen because it was previously proven to be the lower limit of physiological activity (Stewart *et al.* 1972), molting activity (Aiken 1980), and locomotor activity (Ennis 1984) for lobster. Seasonal temperature means (Figures 23 and 25) and seasonal total WD were computed for winter (December 21 of the previous year to March 20), spring (March 21 to June 20), summer (June 21 to September 20), and autumn (September 21 to December 20). Since the range of Massachusetts sea surface temperatures in the summer does not reach 5 °C, summer total WD is completely correlated with summer mean temperature. Thus, to avoid redundancy, summer WD was not used as a predictor in transfer function analysis.

Nine predictor series (annual mean and WD, winter mean and WD, spring mean and WD, summer mean, and autumn mean and WD) were computed from each time series (Woods Hole 1945-1989 and Boston Harbor 1922-1989) to produce 18 predictor series for use in transfer function analysis of Massachusetts landings and catch per trap. The Boston time series was then truncated to 1945-1989 to eliminate the increasing temperature trends from 1922-1944 and the associated requirement for differencing. Compatibility with the Woods Hole time series analysis was thereby enhanced. Results from all 27 transfer function analyses are presented in Table 5 (Appendix Tables 19-24 list univariate and transfer function statistics).

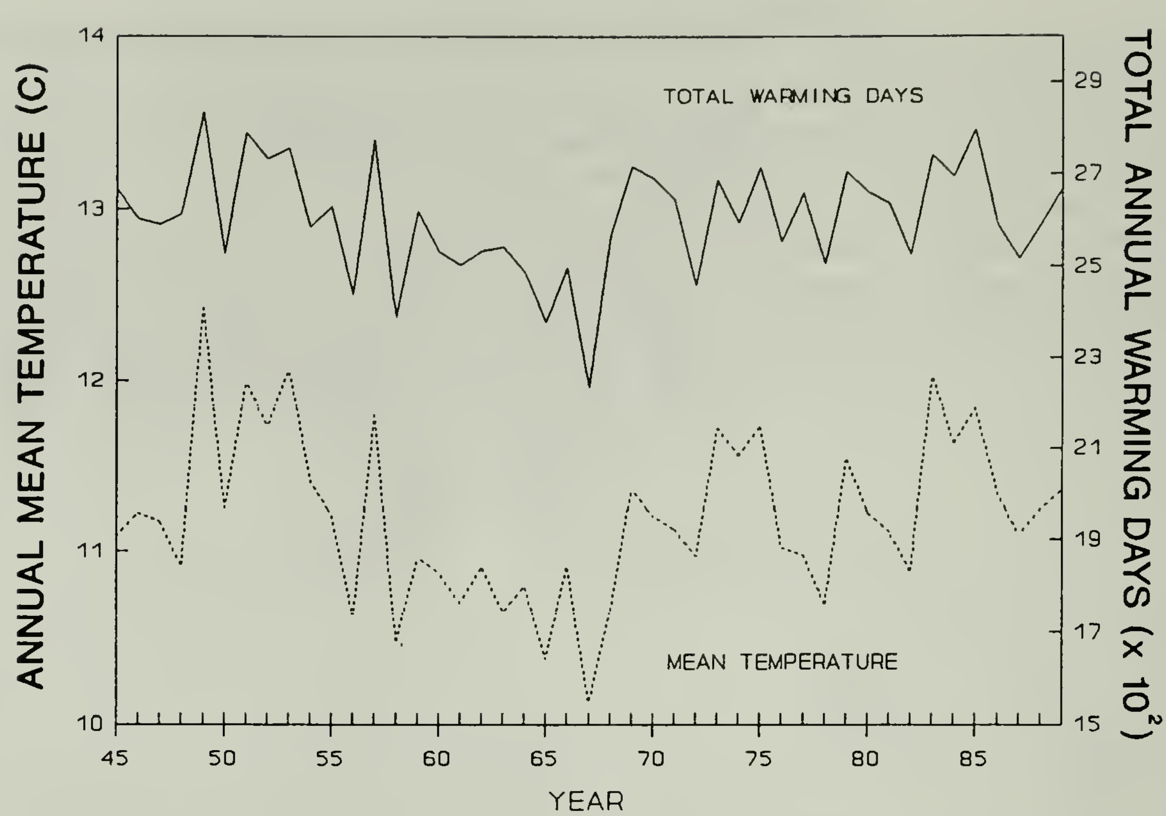


Figure 22. Annual mean sea surface temperature and total warming degree days from Woods Hole 1945-1989. See text for definition of warming day.

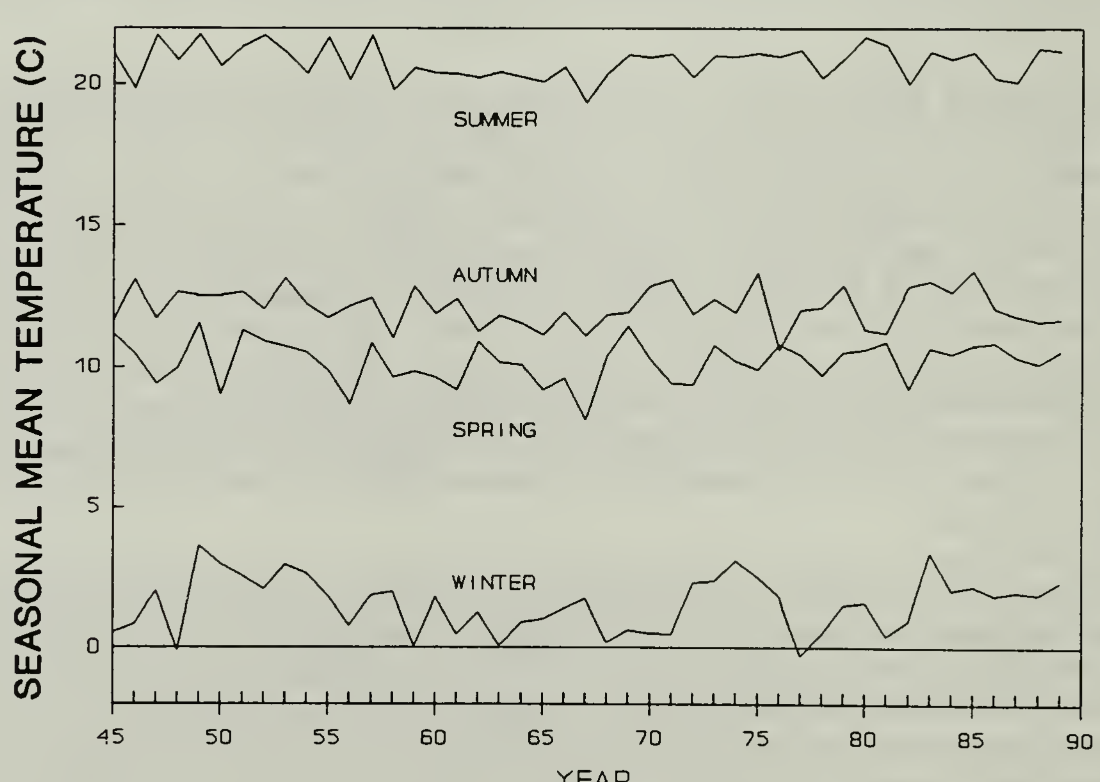


Figure 23. Seasonal mean sea surface temperatures from Woods Hole, 1945-1989.

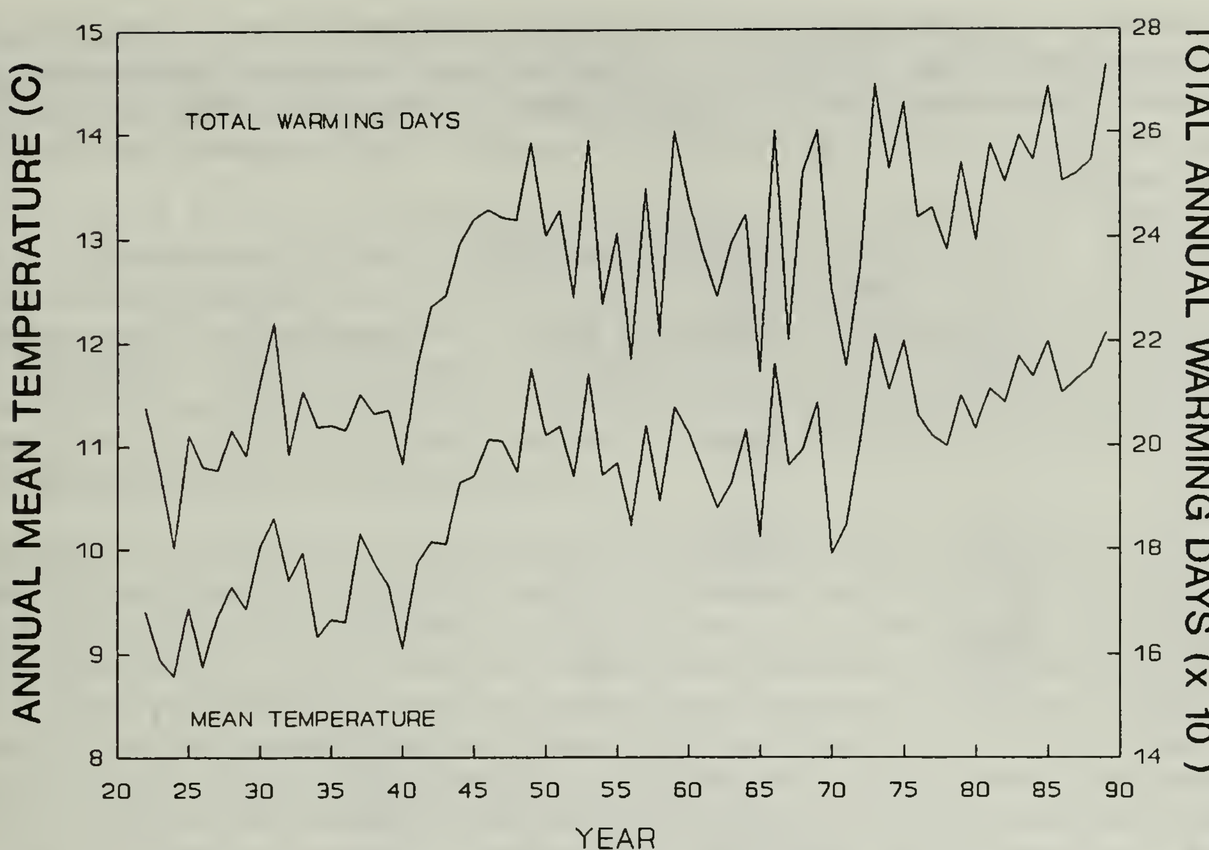


Figure 24. Annual mean sea surface temperature and total warming degree days from Boston Harbor, 1922-1989.

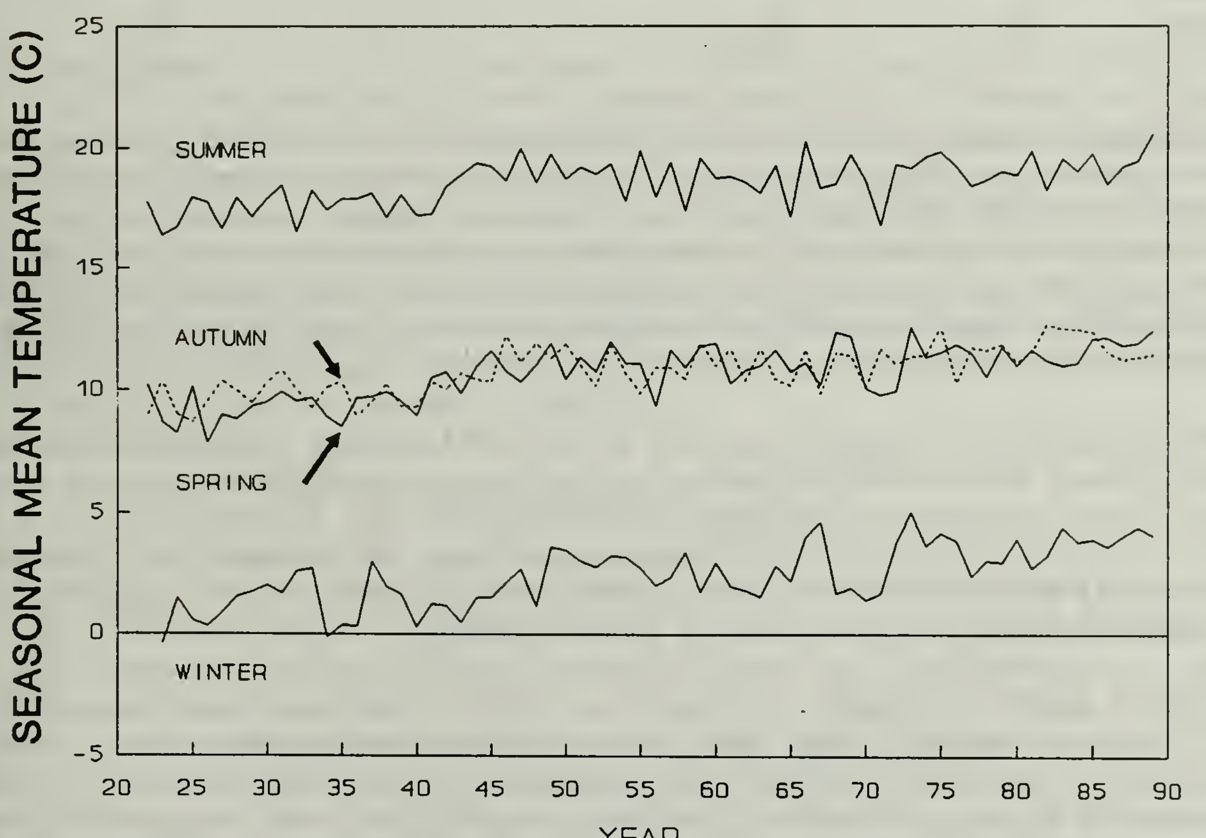


Figure 25. Seasonal mean sea surface temperatures from Boston Harbor 1922-1989.

Table 5. Summary of significant effects of temperature (predictor series) on differenced Massachusetts lobster landings and catch per trap. Numbers indicate lagged effect (in years), parentheses indicate significance at α=0.10, brackets indicate significant crosscorrelation with insignificant effect, and "--" indicates no significant crosscorrelation.

PREDICTOR SERIES	OUTPUT SERIES 1945-1989		1922-1989	
Woods Hole	Landings	Catch per Trap	Landings	Catch per Trap
Annual Mean	[2]	--		
Annual WD	--	0		
Winter Mean	--	2,3,6		
Winter WD	--	--		
Spring Mean	2,3	[1,3]		
Spring WD	2,3	[1],(3)		
Summer Mean	3	0		
Autumn Mean	(0)	--		
Autumn WD	(0)	--		
Boston Harbor				
Annual Mean	0	--	0,2	--
Annual WD	--	--	[0]	[1]
Winter Mean	--	2,3	[6]	2
Winter WD	--	--	--	--
Spring Mean	2,3	--	2	(8)
Spring WD	2,3	--	2	[1]
Summer Mean	0	0	[3]	0
Autumn Mean	0	[4]	--	(4)
Autumn WD	0	[4]	--	(4)

The effects of temperature on landings and catch per trap can be categorized into three groups by their proximity to time of fishery recruitment: 0 year lags indicate an immediate positive effect of temperature on lobster recruitment to the fishery; 1-4 year lags represent effects on pre-recruit, adolescent phase lobster; and 6-8 year lags represent effects on larval, post-larval, and early benthic phase lobster. Since all output variables, landings and catch per pot for both time periods, were differenced, the models describe the *change* in these variables rather than absolute magnitude.

Immediate effects of temperature on 1922-1989 landings were significant for Boston Harbor annual mean; Boston Harbor annual mean, summer mean, and autumn mean and WD had significant immediate effects on 1945-1989 landings. Immediate effects of temperature on catch per trap 1922-1989 were significant for Boston Harbor summer mean; Woods Hole annual WD and summer mean, and Boston Harbor summer mean had significant immediate effects on catch per trap 1945-1989.

Impacts of water temperature on the current-year landings have been well documented (Taylor *et al.* 1957, Dow 1961 1976 and 1977, and Fogarty 1988). Biological mechanisms likely to cause a relationship between temperature and current year landings have been proposed by several authors. McLeese and Wilder (1958) reported increased activity and catchability of lobster at elevated temperatures. Campbell (1983) stated that high temperatures increase the proportion of pre-recruit lobster that molt into legal size. Both responses to elevated temperature, increased catchability and increased molt probability, will cause a short-term increase in yield. Since molting and locomotor activity are negligible below 5 °C, total WD is the most appropriate unit of temperature to distinguish immediate impact on lobster yield.

Temperature's impact on adolescent phase lobster is evident by the effects of Boston Harbor annual mean, spring mean, and spring WD on 1922-1989 landings, and the effects of Boston Harbor spring mean, spring WD, Woods Hole spring mean, spring WD and summer mean on 1945-1989 landings.

Effects lagged 2 and 3 years can be explained by the influence of temperature on lobster growth (Templeman 1936a and 1948, Aiken 1980, Campbell 1983, and Ennis 1986). Rapid growth enhances survival by reducing the period in which lobster are vulnerable to size-dependent mortality (Ricker and Foerster 1948 and Beverton and Holt 1957). Predation is commonly size-dependent (i.e. each predator has a maximum prey size). A lobster cohort that quickly grows to less vulnerable size will experience less predation than a slow growing cohort. Thus, high temperatures decrease mortality of adolescent lobster and increase recruitment in subsequent years.

Temperature's influence on larval lobster recruitment and survival is suggested by the significant 6-year lagged effect of Woods Hole winter mean on 1945-1989 catch per trap. The crosscorrelation of 1922-1989 catch per trap and 8-year lagged Boston harbor spring mean temperature did not produce a significant transfer function, but may suggest a relationship (since 1945-1989 is a relatively short annual series with respect to the requirements of time series analysis, the power of these transfer function analyses are substantially limited at high lags). Similar to its effects on adolescent lobster, temperature increases larval survival through developmental acceleration. Because planktonic larvae are subject to a high rate of mortality, reduction in duration of the planktonic stage by accelerated development will increase survival (Caddy 1979, Harding *et al.* 1983, and Ennis 1986). Researchers have shown that, within limits, larval development is accelerated by high water temperatures (Hadley 1906, Templeman 1936b, and 1948, and Templeman and Tibbo 1945).

The 6-year lagged effect of winter mean temperature may be produced by temperature's influence on survival of newly settled post-larvae. Flowers and Saila (1972) found a significant correlation of Maine lobster landings with the sum of seasonal mean water temperatures (December to May) lagged 6, 7, and 8 years. They state that winter temperature may be more important to survival of a newly settled cohort than summer temperatures during the planktonic phase. Other researchers have found similar lagged relationships between Maine landings and Boothbay Harbor temperatures lagged 6 to 8 years (Dow 1976 1977 and 1980, Orach-Meza and Saila 1978, and Fogarty 1988). Flowers and Saila (1972) stated that lagged temperature is more important than current temperature for the development of yield estimating equations.

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REFERENCES CITED

Aiken, D. E. 1980. Molting and growth. In J. S. Cobb and B. F. Phillips Eds. The Biology and Management of Lobsters Vol. I. Academic Press. 91-163.

Aiken and Waddy. 1986. Environmental influence on recruitment of the American lobster, *Homarus americanus*: a perspective. Can J. Fish. Aquat. Sci. 43:2258-2270.

Beverton, R. J. H. and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Reports et Proces-Verbaux des Reunions 140:67-83.

Beverton, R. J. H. and S. J. Holt. 1957. On the Dynamics of Exploited Fish Populations. Her Majesty's Stationary Office. London. 533 p.

Bodammer, J. E. and T. K. Sawyer. 1981. Aufwuchs protozoa and bacteria on the gills of the rock crab, *Cancer irroratus* Say: a survey by light and electron microscopy. Journal of Protozoology, 28:35-46.

Boehm, P. 1984. Organic pollutant biogeochemistry studies northeast U.S. marine environment. Final Report Contract No. NA-83-FA-C-0002 to National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Monitoring Program, Sandy Hook Laboratory, Highlands, New Jersey. 61 p.

Box, G. E. P. and G. M. Jenkins. 1976. Time Series Analysis forecasting and control. Holden-Day. 575 p.

Caddy, J. F. 1979. The influence of variations in the seasonal temperature regime on survival of larval stages of the American lobster (*Homarus americanus*) in the southern Gulf of Saint Lawrence. Rapp. P.-v Reun. Cons. int. Explor. Mer. 175:204-216.

Campbell, A. 1983. Growth of tagged lobsters (*Homarus americanus*) off Port Maitland, Nova Scotia, 1948-80. Can. Tech. Rep. Fish. Aquat. Sci. No. 1232:1-10.

Campbell, A. 1986. Migratory movements of ovigerous lobsters, *Homarus americanus*, tagged off Grand Manan, Eastern Canada. Can. J. Aquat. Sci. 43:2197-2205.

Colton, J. B. 1964. History of oceanography in the offshore waters of the Gulf of Maine. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries No. 496. 18p.

Colton, J. B. and R. R. Stoddard. 1973. Bottom water temperatures on the Continental Shelf, Nova Scotia to New Jersey. NOAA Technical Report NMFS CIRC-376.

Cooper, R. A. and J. R. Uzmann. 1971. Migrations and growth of deep-sea lobsters, *Homarus americanus*. Science. 171:288-290.

Dow, R. I. 1961. Some factors influencing Maine lobster landings. Commercial Fisheries Review 23(9):1-11.

Dow, R. L. 1976. Effects of climatic cycles on the relative abundance and availability of commercial marine and estuarine species. J. Cons. int. Explor. Mer. 37(3):274-280.

Dow, R. L. 1977. Relationship of sea surface temperature to American and European lobster landings. J. Cons. int. Explor. Mer 37(2):186-191.

Dow, R. L. 1980. The clawed lobster fisheries. In J. S. Cobb and B. F. Phillips Eds. The Biology and Management of Lobsters Vol. II. Academic Press. 265-316.

Dow, R. L., F. W. Bell, and D. M. Harriman. 1975. Bioeconomic relationships for the Maine lobster fishery with consideration of alternative management schemes. NOAA Technical Report, NMFS SSRF-683. 44 p.

Ellis, J. P., B. C. Kelley, P. Stoffers, M.G. Fitzgerald, and C. P. Summerhayes. 1977. Data file: New Bedford Harbor, Massachusetts. Woods Hole Oceanographic Institution Technical Report WHOI-77-73.

Ennis, G. P. 1984. Territorial behavior of the American lobster *Homarus americanus*. Trans. Am. Fish. Soc. 113(3):330-335.

Ennis, G. P. 1986. Stock definition, recruitment variability, and larval recruitment processes in the American lobster, *Homarus americanus*: a review. Can. J. Aquat. Sci. 43:2072-2084.

Estrella, B. T. 1984. Black gill and shell disease in American lobster (*Homarus americanus*) as indicators of pollution in Massachusetts Bay and Buzzards Bay, Massachusetts. Massachusetts Division of Marine Fisheries. Publ. No 14049-19-125-5-85-C.R. 17p.

Estrella, B. T. and D. J. McKiernan. 1989. Catch per unit effort and biological parameters from the Massachusetts coastal lobster (*Homarus americanus*) resource: description and trends. NOAA Technical Report NMFS 81, 21 p.

Estrella, B.T. and S.X. Cadrin. 1989. Massachusetts Coastal Commercial lobster trap sampling program, May-November, 1988. Massachusetts Division of Marine Fisheries, 23 p.

Estrella, B.T. and S.X. Cadrin. 1990. Massachusetts Coastal Commercial lobster trap sampling program, May-November, 1989. Massachusetts Division of Marine Fisheries, 21 p.

Fair, J.J., Jr. 1977. Lobster investigations in management area I: Southern Gulf of Maine. NOAA, NMFS State-Federal Relationships Division, Mass. Lobster Report No. 8., April 21, 1975-April 20, 1977, 8 p. and Appendix, 14 p.

Flowers, J. M. and S. B. Saila. 1972. An analysis of temperature effects on the inshore lobster fishery. J. Fish. Res. Bd. Can. 29(8):1221-1228.

Fogarty, M. J. 1988. Time series models of the Maine lobster fishery: The effect of temperature. Ca. J. Aquat. Sci. 45(7):1145-1153.

Getchell, R. G. 1989. Bacterial shell disease in crustaceans: a review. Journal of Shellfish Research 8(11):1-6.

Gilbert, T. R., A. M. Clay, and A. Barker. 1973. Site selection and study of ecological effects of disposal of dredged materials in Buzzards Bay, Massachusetts. Prepared for Department of the Army, New England Division, Corps of Engineers by New England Aquarium. 70 p.

Gilbert, T. R., A. M. Clay, and C. A. Karp. 1976. Distribution of polluted materials in Massachusetts Bay. New England Aquarium Corporation, Central Wharf, Boston, MA. Prepared for the Massachusetts Division of Water Pollution Control. 173 p.

Gopalan, V. K. and J. S. Young. 1975. Incidence of shell disease in shrimps in the New York Bight. Marine Pollution Bulletin, 6:149-153.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. Pt. 1, fish population analysis. FAO Manuals in Fisheries Science 4, 154 p.

Hadley, P. B. 1906. Regarding the rate of growth of the American lobster (*Homarus americanus*) Annual report of Commissioners of Inland Fisheries of Rhode Island. 24:153-235.

Harding, G. C., K. F. Drinkwater, and W. P. Vass. 1983. Factors influencing the size of American lobster (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. Can. J. Fish. Aquat. Sci. 40(2):168-184.

Hughes, J. T. and G. C. Matthiessen. 1962. Observations on the biology of the American lobster *Homarus americanus*. Limnology and Oceanography 7, 414-421.

Kolek, A. and R. Ceurvels. 1981. Polychlorinated biphenyl (PCB) analyses of marine organisms in the New Bedford area, 1976-80. Massachusetts Division of Marine Fisheries, 34 p.

Krouse, J.S. 1976. Incidence of cull lobsters, *Homarus americanus*, in commercial and research catches off the Maine coast. Fish. Bull. 74(4): 719-724.

McLeese, D. W. and D. G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Bd. Can. 15(6):1345-1354.

Malloy, S. C. 1978. Bacteria induced shell disease of lobster (*Homarus americanus*). Journal of Wildlife Diseases, 14:2-10.

Nie, N.H. 1983. SPSS: statistical package for the social sciences, McGraw-Hill, New York, 806 p.

Orach-Meza, F. L. and S. B. Saila. 1978. Application of a polynomial distributed lag model to the Maine lobster fishery. Trans. Am. Fish. Soc. 107(3)402-411.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using Cohort analysis. Research Bulletin Int. Comm. NW Atlant. Fish. 9:65-74.

Ricker, W. E. and R. E. Foerster. 1948. Computation of fish production, a symposium on fish populations. Bull. Bingham Oceanogr. Coll. 11(4):173-211.

Rosen, B. 1970. Shell disease of aquatic crustaceans. In "A symposium on disease of fishes and shellfishes" (S. F. Snieszko, ed), American Fisheries Society Special Publication, 5:409-415.

Saila, S. B. and J. M. Flowers. 1968. Movements and behaviour of berried female lobsters displaced from offshore areas to Narragansett Bay, Rhode Island. J. Cons. perm. int. Explor. Mer. 31(3):342-351.

Sawyer, T. K. 1982. Distribution and seasonal incidence of "black gill" in the rock crab, *Cancer irroratus*. In "Ecological Stress and the New York Bight: Science and Management" (G. F. Mayer, ed.). Estuarine Research Federation, Columbia, South Carolina, 199-211.

Sawyer, T. K., E. J. Lewis, M. Galasso, S. Bodammer, J. Ziskowski, D. Lear, M. O'Malley, and S. Smith. 1983. Black gill conditions in the rock crab *Cancer irroratus*, as indicators of ocean dumping in Atlantic coastal waters of the United States. Rapp. R. -v. Reun. Cons. int. Explor. Mer. 182:91-95.

Sindermann, C. J. 1970. Principal diseases of marine fish and shellfish. Academic Press, New York. 368 p.

Sindermann, C.J., F. Csulak, T.K. Sawyer, R.A. Bullis, D.W. Engel, B.T. Estrella, E.J. Noga, J.B. Pearce, J.C. Rugg, R. Runyon, J.A. Tiedemann, and R.R. Young. 1989. Shell disease of crustaceans in the New York Bight. NOAA Tech. Memo. NMFS-F/NEC-74, 47pp.

Sindermann, C. J. 1989. The shell disease syndrome in marine crustaceans. NOAA Tech. Memo. NMFS-F/NEC-64. 43 p.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Company, San Francisco, 776 p.

Steele, R. G. and J. H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill, New York, 481 p.

Stewart, J. E. 1980. Diseases. In "The Biology and Management of Lobsters" (J. S. Cobb and B. F. Phillips, ed.). Academic Press. New York, Vol. 1:301-342.

Stewart, J. E., G. W. Horner, and B. Arie. 1972. Effects of temperature, food, and starvation on several physiological parameters of the lobster *Homarus americanus*. J. Fish. Res. Bd. Can. 29(4)439-442.

Taylor, C. C., H. B. Bigelow and H. W. Graham. 1957. Climatic trends and the distribution of marine animals in New England. Fishery Bulletin 115(57):293-334.

Templeman, W. 1936a. Local differences in the life history of the lobster (*Homarus americanus*) on the coast of the maritime provinces of Canada. J. Biol. Bd. Can. 2(1):41-88.

Templeman, W. 1936b. The influence of temperature, salinity, light and food conditions on the survival and growth of the larvae of the lobster (*Homarus americanus*) J. Biol. Bd. Can. 2(5):485-497.

Templeman, W. and S. N. Tibbo. 1945. Lobster investigations in Newfoundland 1938 to 1941. Newfoundland Dept. Nat. Res. Research Bull. 16. 98 p.

Weaver, G. 1984. PCB pollution in and around New Bedford, Massachusetts. Envir. Sci. Technol. 18(1):22A-27A.

Young, J. S. and J. B. Pearce. 1975. Shell disease in crabs and lobsters from New York Bight. Marine Pollution Bulletin, 6:101-105.

APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751	0.826
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827
Boston Harbor	—	—	—	1.108	1.254	1.096	1.058	1.057	1.123	1.224
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.509	0.695	0.716
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408
Boston Harbor	—	—	—	0.901	1.162	1.138	1.156	0.639	0.966	1.103
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	1.473	1.401	1.624	1.389	1.705	1.899	1.873	1.736	2.297	2.216
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867
Boston Harbor	—	—	—	2.773	3.038	3.314	3.334	1.959	3.104	3.382
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8
Boston Harbor	—	—	—	1.4	1.2	2.0	1.7	2.0	2.1	2.7
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057	0.073
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005
Boston Harbor	—	—	—	0.009	0.007	0.015	0.012	0.012	0.010	0.028
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211	0.282
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109
Beverly–Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023
Boston Harbor	—	—	—	0.030	0.025	0.050	0.037	0.038	0.043	0.075
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	86	87	86	86	88	88	89	90	88	87
Cape Ann	91	92	87	89	87	87	88	90	84	81
Beverly–Salem	89	92	94	88	96	96	97	98	96	95
Boston Harbor	—	—	—	93	94	96	96	96	96	95
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50
Buzzards Bay	98	96	96	94	96	97	97	97	95	94

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	1.58 *	1.7	1.66	1.66	1.76	1.80	1.90	1.86	1.80	1.76
	79% **	82	81%	81%	83%	84%	85%	84%	83%	83%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%
Beverly–Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%
Boston Harbor	—	—	—	2.52	3.59	2.60	2.77	2.86	2.96	3.00
	—	—	—	92%	97%	93%	94%	94%	95%	95%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	1.35 *	1.4	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50
	74% **	77	75%	76%	77%	78%	79%	79%	78%	78%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%
Beverly–Salem	1.59	1.7	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%
Boston Harbor	—	—	—	1.82	1.75	1.92	1.88	1.84	1.94	1.87
	—	—	—	84%	83%	85%	85%	84%	86%	85%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04
Beverly–Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86
Boston Harbor	—	—	—	1.77	1.70	1.80	1.87	1.83	1.94	1.86
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97

Table 10. Estimated exploitation rate (μ), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51
Beverly–Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85
Boston Harbor	—	—	—	0.82	0.81	0.80	0.84	0.84	0.86	0.85
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3
Beverly–Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3
Boston Harbor	—	—	—	86.8	86.9	86.4	86.6	87.5	88.0	88.1
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0

Table 12. Mean carapace length (mm), by state and region for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5	77.6
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8
Beverly–Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1
Boston Harbor	—	—	—	77.1	76.9	76.9	76.5	75.6	76.8	77.4
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	88.5	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5	88.0
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1
Beverly–Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5
Boston Harbor	—	—	—	82.1	84.0	81.3	82.3	83.7	83.0	83.8
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	10.0	10.8	10.7	14.8	18.1	20.9	17.0	18.2	19.2	18.6
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7
Beverly–Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3
Boston Harbor	—	—	—	13.3	19.3	19.1	16.9	16.3	13.8	14.7
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6

Table 15. Cull rate (percent), by state and region, for all legal–sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9	15.4
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7
Beverly–Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6
Boston Harbor	—	—	—	10.1	16.2	15.8	12.9	13.1	9.9	9.9
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2	15.6
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2
Beverly–Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8
Boston Harbor	—	—	—	10.2	16.2	15.7	12.8	13.1	9.9	9.9
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4

Table 17. Cull rate (percent), by state and region, for sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3
Beverly–Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2
Boston Harbor	—	—	—	14.5	20.5	20.0	18.0	18.0	15.2	16.4
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1990.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09
Beverly–Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29
Boston Harbor	—	—	—	0.00	0.03	0.03	0.23	0.09	0.03	0.04
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18

Table 19. Transfer functions of Massachusetts annual lobster landings (1st order differenced and $\log_e$ transformed) 1944-1989 using Woods Hole sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$; ** denotes significance at $\alpha = 0.10$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.416	0.1384	-3.01*	0.017043
Transfer function with **Annual Mean Temperature**, ARIMA (2,0,0)					
ϕ_1	1	-0.474	0.1394	-3.40*	0.015169
ω_2	2	0.363E-1	0.0319	1.14	
Transfer function with **Spring Mean Temperature**					
ϕ_1	1	-0.344	0.1572	-2.19*	0.013098
ω_2	2	0.533E-1	0.0236	2.26*	
ω_3	3	-0.656E-1	0.0232	-2.83*	
Transfer function with **Spring Warming Degree Days**					
ϕ_1	1	-0.319	0.1594	-2.00*	0.012695
ω_2	2	0.696E-3	0.0003	2.30*	
ω_3	3	-0.934E-3	0.0003	-3.16*	
Transfer function with **Summer Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.462	0.1464	-3.16*	0.014316
ω_3	3	-0.710E-1	0.0261	-2.72*	
Transfer function with **Autumn Mean Temperature**					
ϕ_1	1	-0.468	0.1394	-3.35*	0.014141
ω_0	0	0.467E-1	0.0247	1.89**	
Transfer function with **Autumn Warming Degree Days**					
ϕ_1	1	-0.468	0.1393	-3.36*	0.013995
ω_0	0	0.597E-3	0.0003	2.01**	

Table 20. Transfer functions of Massachusetts annual lobster catch per trap (1st order differenced and $\log_e$ transformed) 1944-1989 using Woods Hole sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$; ** denotes significance at $\alpha = 0.10$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.478	0.1329	-3.60*	0.016388
Transfer function with **Annual Warming Degree Days**, ARIMA (0,1,1)					
ϕ_1	1	-0.478	0.1328	-3.60*	0.013471
ω_0	0	0.392E-3	0.0001	2.96*	
Transfer function with **Winter Mean Temperature**, ARIMA (1,0,1)					
ϕ_1	1	-0.438	0.1524	-2.88*	0.011520
ω_2	2	0.657E-1	0.0174	3.77*	
ω_3	3	-0.485E-1	0.0174	-2.79*	
ω_6	6	0.373E-1	0.0144	2.59*	
Transfer function with **Spring Mean Temperature**					
ϕ_1	1	-0.423	0.1530	-2.77*	0.015659
ω_1	1	-0.170E-1	0.0249	-0.68	
ω_3	3	-0.328E-1	0.0243	-1.35	
Transfer function with **Spring Warming Degree Days**					
ϕ_1	1	-0.393	0.1561	-2.52*	0.015255
ω_1	1	-0.299E-3	0.0003	-0.92	
ω_3	3	-0.553E-3	0.0003	-1.74**	
Transfer function with **Summer Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.426	0.1446	-2.95*	0.014346
ω_0	0	0.610E-1	0.0267	2.28*	

Table 21. Transfer functions of Massachusetts annual lobster landings (1st order differenced and $\log_e$ transformed) 1922-1989 using Boston Harbor sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.391	0.0970	-4.03*	0.021214
Transfer function with **Annual Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.355	0.1182	-3.00*	0.018458
ω_0	0	0.414E-1	0.0173	2.39*	
ω_2	2	0.766E-1	0.0324	2.36*	
Transfer function with **Annual Warming Degree Days**, ARIMA (0,1,1)					
ϕ_1	1	-0.339	0.1202	-2.82*	0.019430
ω_0	0	0.178E-3	0.0001	1.53	
Transfer function with **Winter Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.360	0.1258	-2.86*	0.020015
ω_6	6	0.293E-1	0.0178	1.65	
Transfer function with **Spring Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.352	0.1182	-2.98*	0.018087
ω_2	2	0.494E-1	0.0187	2.64*	
Transfer function with **Spring Warming Degree Days**, ARIMA (0,1,1)					
ϕ_1	1	-0.322	0.1197	-2.69*	0.018086
ω_2	2	0.604E-3	0.0002	2.69*	
Transfer function with **Summer Mean Temperature**, ARIMA (1,1,1)					
ϕ_1	1	-0.344	0.1240	-2.77*	0.019626
ω_3	3	-0.302E-1	0.0189	-1.60	

Table 22. Transfer functions of Massachusetts annual lobster catch per trap (1st order differenced and $\log_e$ transformed) 1922-1989 using Boston Harbor sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$; ** denotes significance at $\alpha = 0.10$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.421	0.0980	-4.30*	0.015904
Transfer function with **Annual Warming Degree Days**, ARIMA (0,1,1)					
ϕ_1	1	-0.285	0.1220	-2.33*	0.016101
ω_1	1	-0.128E-3	0.0001	-1.23	
Transfer function with **Winter Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.299	0.1226	-2.44*	0.015626
ω_2	2	0.310E-1	0.0153	2.03*	
Transfer function with **Spring Mean Temperature**, ARIMA (0,1,1)					
ϕ_1	1	-0.330	0.1269	-2.60*	0.016556
ω_8	8	-0.305E-1	0.180	-1.70**	
Transfer function with **Spring Warming Degree Days**, ARIMA (0,1,1)					
ϕ_1	1	-0.293	0.1200	-2.44*	0.016025
ω_1	1	-0.285E-3	0.0002	-1.34	
Transfer function with **Summer Mean Temperature**, ARIMA (1,1,1)					
ϕ_1	1	-0.250	0.1174	-2.13*	0.014745
ω_0	0	0.433E-1	0.0151	2.86*	
Transfer function with **Autumn Mean Temperature**					
ϕ_1	1	-0.313	0.1229	-2.54*	0.015835
ω_4	4	-0.351E-1	0.0189	-1.85**	
Transfer function with **Autumn Warming Degree Days**					
ϕ_1	1	-0.319	0.1226	-2.60*	0.015786
ω_4	4	-0.454E-3	0.0002	-1.90**	

Table 23. Transfer functions of Massachusetts annual lobster landings (1st order differenced and $\log_e$ transformed) 1945-1989 using Boston Harbor sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.416	0.1384	-3.01*	0.017043
Transfer function with **Annual Mean Temperature**, ARIMA ((2),0,0)					
ϕ_1	1	-0.474	0.1396	-3.39*	0.013578
ω_0	0	0.620E-1	0.0273	2.27*	
Transfer function with **Spring Mean Temperature**					
ϕ_1	1	-0.371	0.1515	-2.45*	0.013991
ω_2	2	0.537E-1	0.0249	2.16*	
ω_3	3	-0.514E-1	0.0252	-2.04*	
Transfer function with **Spring Warming Degree Days**					
ϕ_1	1	-0.368	0.1515	-2.43*	0.014080
ω_2	2	0.585E-3	0.0003	2.03*	
ω_3	3	-0.598E-3	0.0003	-2.05*	
Transfer function with **Summer Mean Temperature**, ARIMA (1,0,0)					
ϕ_1	1	-0.419	0.1458	-2.87*	0.013706
ω_0	0	0.559E-1	0.0246	2.28*	
Transfer function with **Autumn Mean Temperature**, ARIMA ((3),0,0)					
ϕ_1	1	-0.541	0.1309	-4.13*	0.012954
ω_0	0	0.560E-1	0.0205	2.73*	
Transfer function with **Autumn Warming Degree Days**, ARIMA ((2),0,0)					
ϕ_1	1	-0.538	0.1319	-4.08*	0.012855
ω_0	0	0.685E-3	0.0002	2.79*	

Table 24. Transfer functions of Massachusetts annual lobster catch per trap (1st order differenced and $\log_e$ transformed) 1945-1989 using Boston Harbor sea surface temperatures as independent variables. Note: * denotes significance at $\alpha = 0.05$.

Parameter	Lag	Estimate	Standard Error	T-ratio	Residual Mean Square
Univariate Model					
ϕ_1	1	-0.478	0.1329	-3.60*	0.016388
Transfer function with **Winter Mean Temperature**, ARIMA (1,0,0)					
ϕ_1	1	-0.499	0.1362	-3.66*	0.013152
ω_2	2	0.594E-1	0.0193	3.08*	
ω_3	3	-0.404E-1	0.0189	-2.14*	
Transfer function with **Summer Mean Temperature**, ARIMA (1,0,0)					
ϕ_1	1	-0.375	0.1474	-2.55*	0.014563
ω_0	0	0.674E-1	0.0256	2.63*	
Transfer function with **Autumn Mean Temperature**, ARIMA ((3),0,0)					
ϕ_1	1	-0.476	0.1448	-3.29*	0.015928
ω_4	4	-0.253E-1	0.0233	-1.09	
Transfer function with **Autumn Warming Degree Days**, ARIMA ((2),0,0)					
ϕ_1	1	-0.486	0.1433	-3.39*	0.016011
ω_4	4	-0.258E-3	0.0003	-0.94	